A Survey of Cost Risk Methods for Project Management

PMI Risk SIG Project Risk Symposium

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Outline

- Definitions
- Cost risk
  - Historical cost growth
  - Cost risk model architecture
  - Cost risk model types
- Risk management
  - The risk cube method
- Schedule risk
  - How networks operate- some "toy problems"
  - Schedule and cost growth
  - The distribution of schedule risk
- Conclusion

We will try to get through *Risk Management* … a presentation on Schedule Risk Follows!

Introduction

Why Do Risk?

- Risk is a significant part of cost and schedule estimation, and is used to adjust estimates, budgets and schedules for anticipated cost growth
- Incorrect treatment of risk, while better than ignoring it, creates a false sense of security
- This brief will define risk, discuss it in general, and describe several approaches to estimation
- This brief cannot possibly teach risk to you, but hopefully it will both scare you and intrigue you[1]

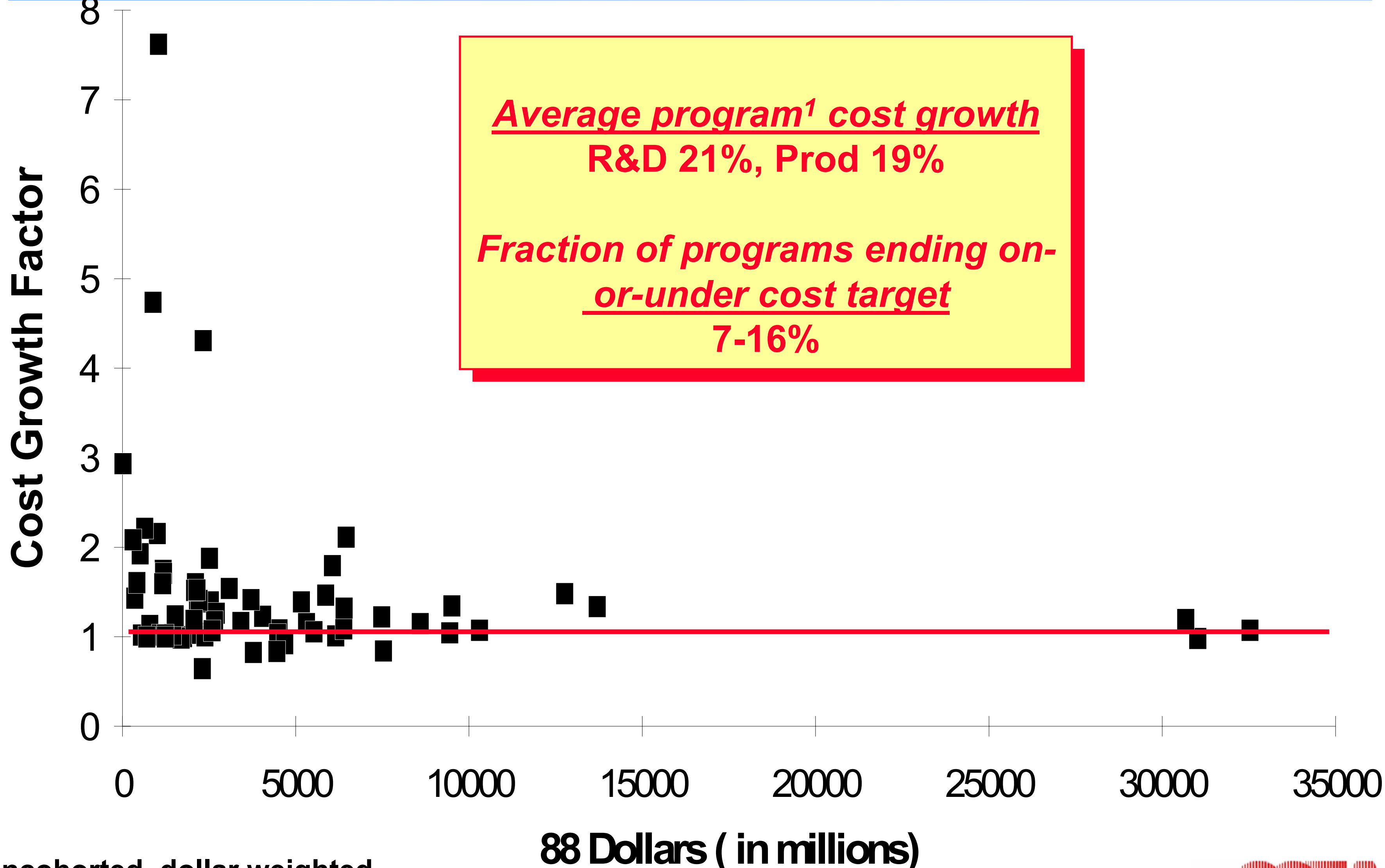
1 Another tutorial is in Module 9 of the SCEA Certification Training – *CostPROF*, and further resources are listed in the back of the brief

Cost Risk

Historical Cost Growth

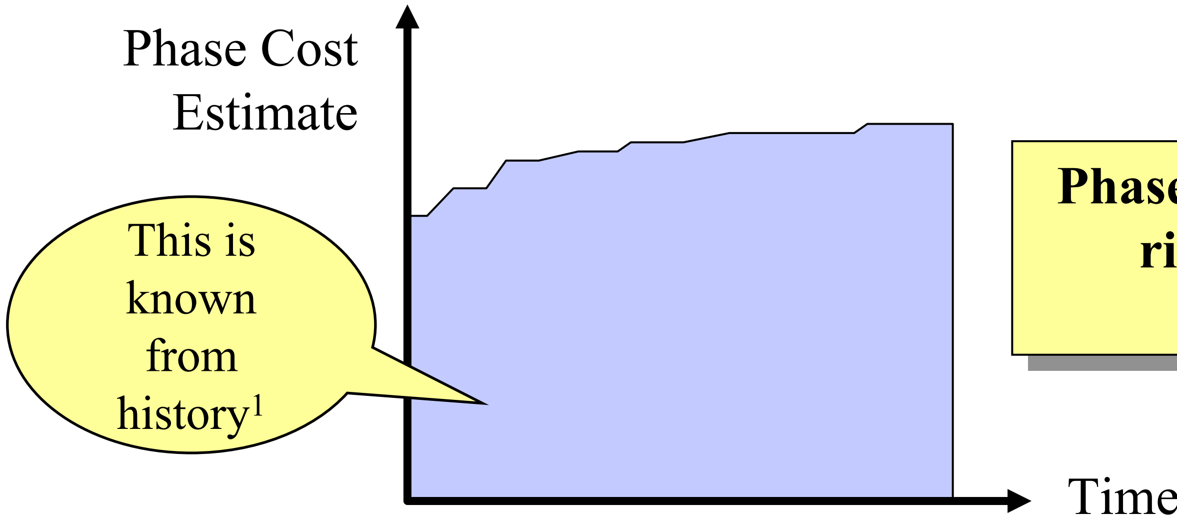
Historical Cost Growth

Note: This pattern appears to be fractal



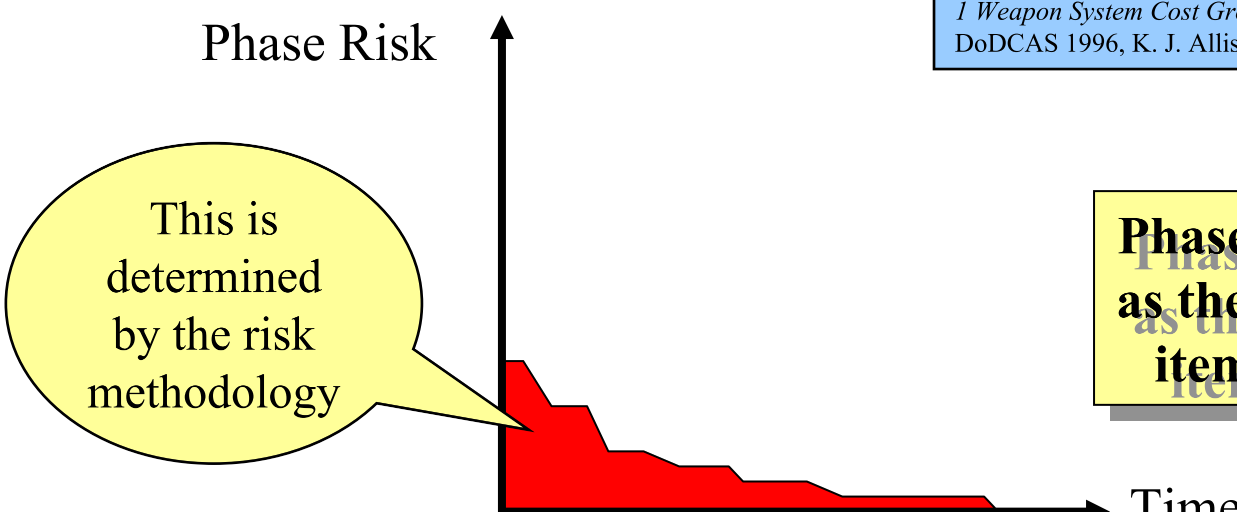
1 Uncohorted, dollar weighted

Progression of Phase Cost and Risk



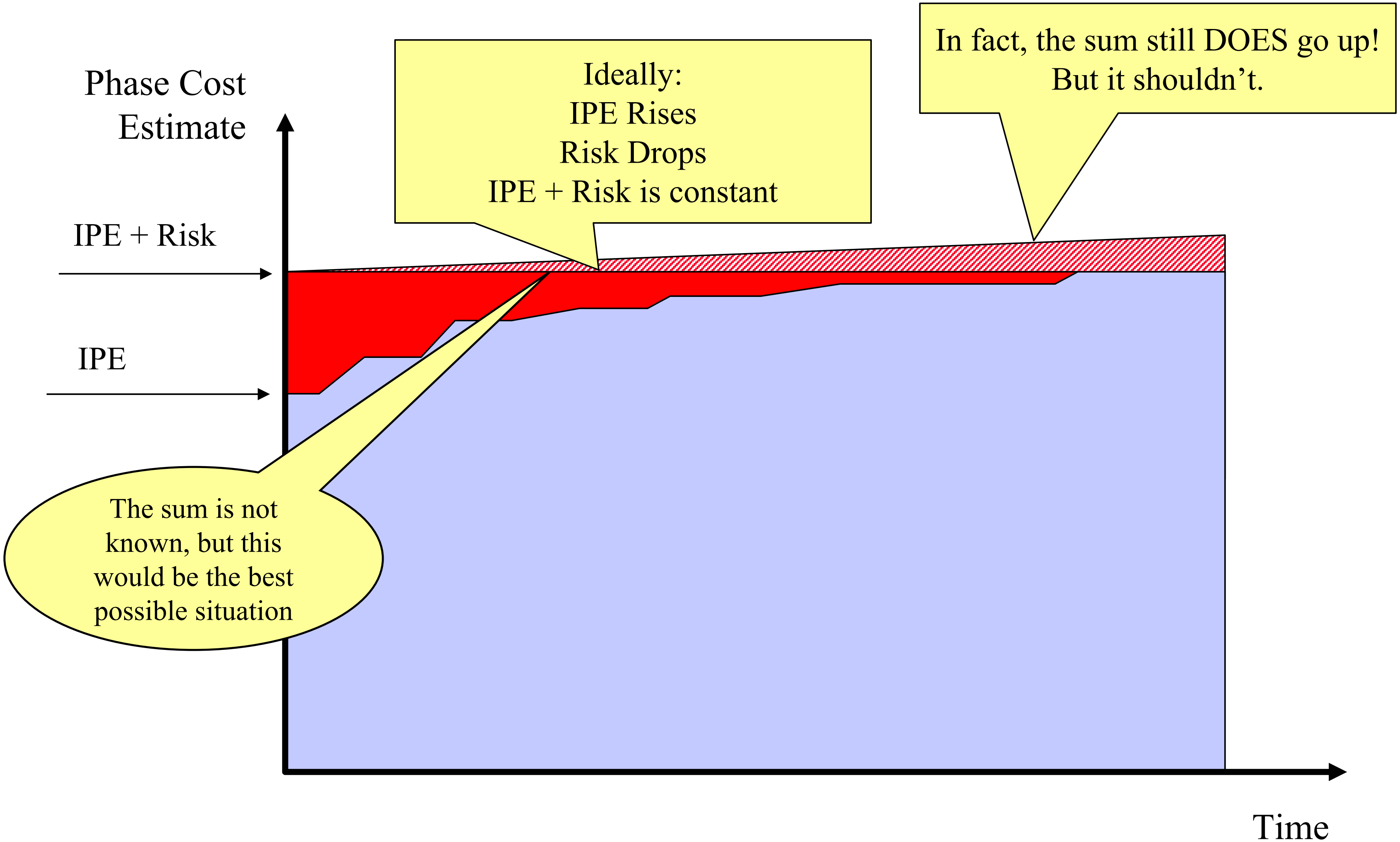
Phase cost estimates rise as risk is 'realized'

1 Weapon System Cost Growth As a Function of Maturity, DoDCAS 1996, K. J. Allison, R. L. Coleman

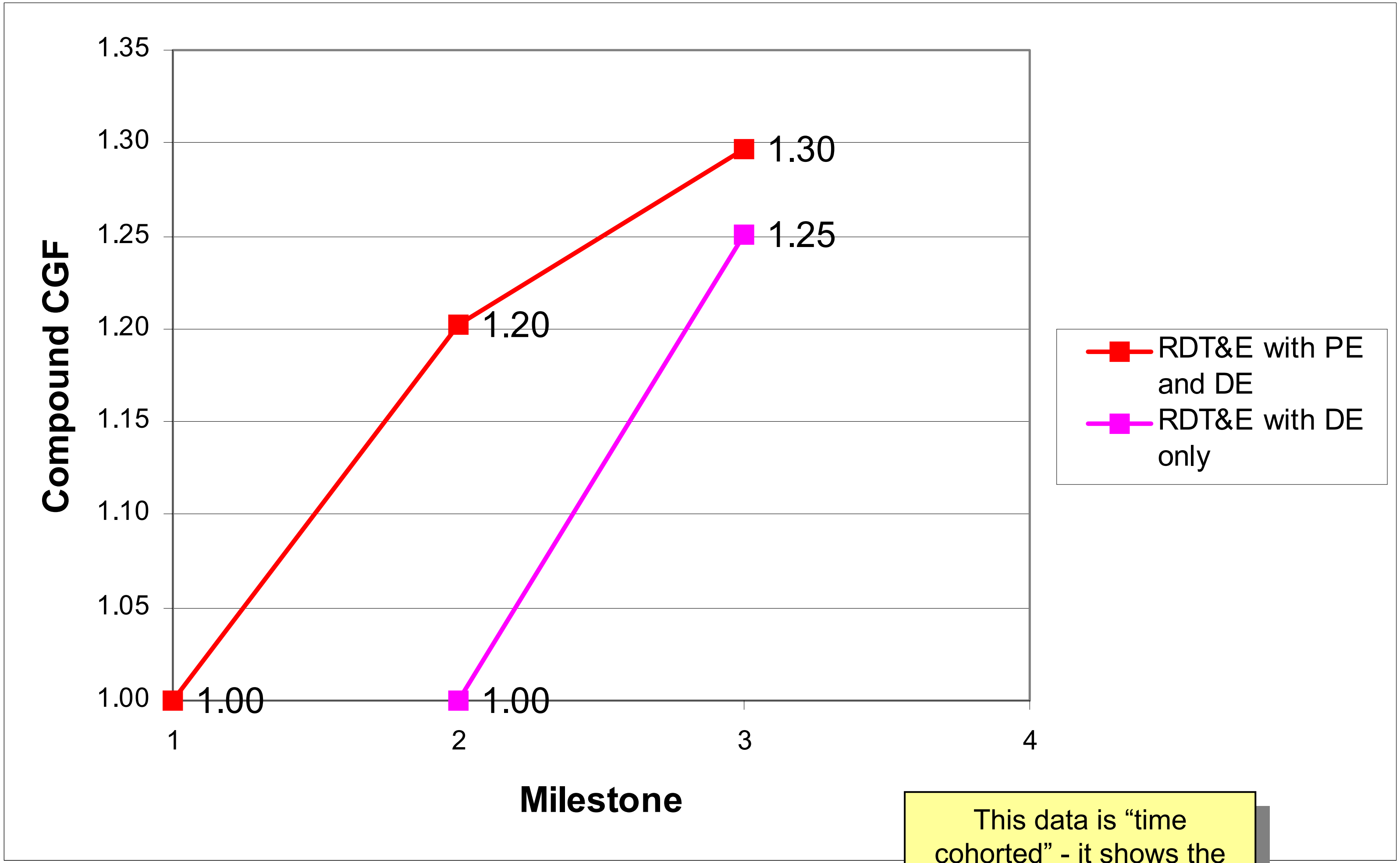


Phase risk estimates fall as the scores assigned to items drop over time

Progression of Cost + Risk

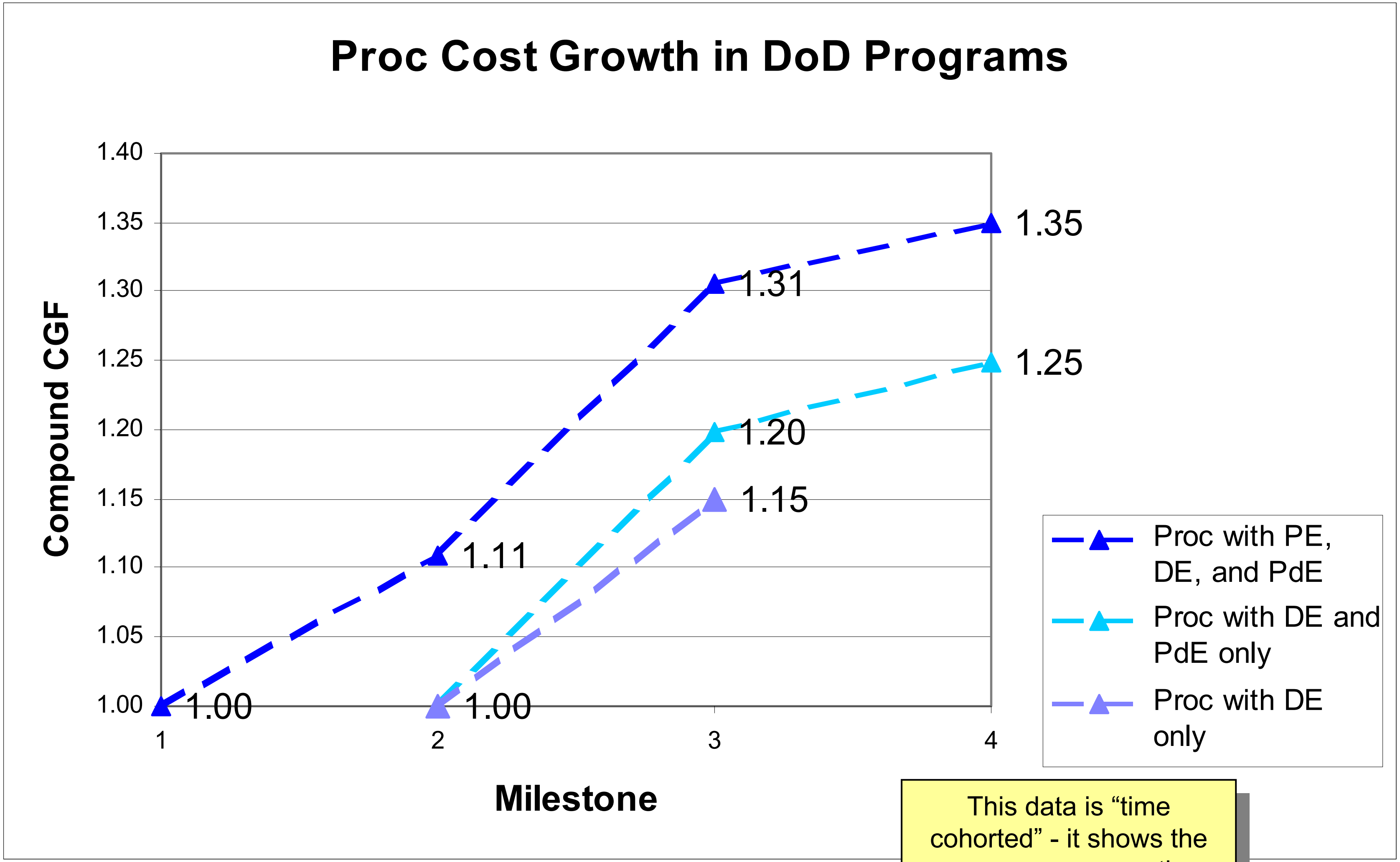


DoD RDT&E Cost Growth



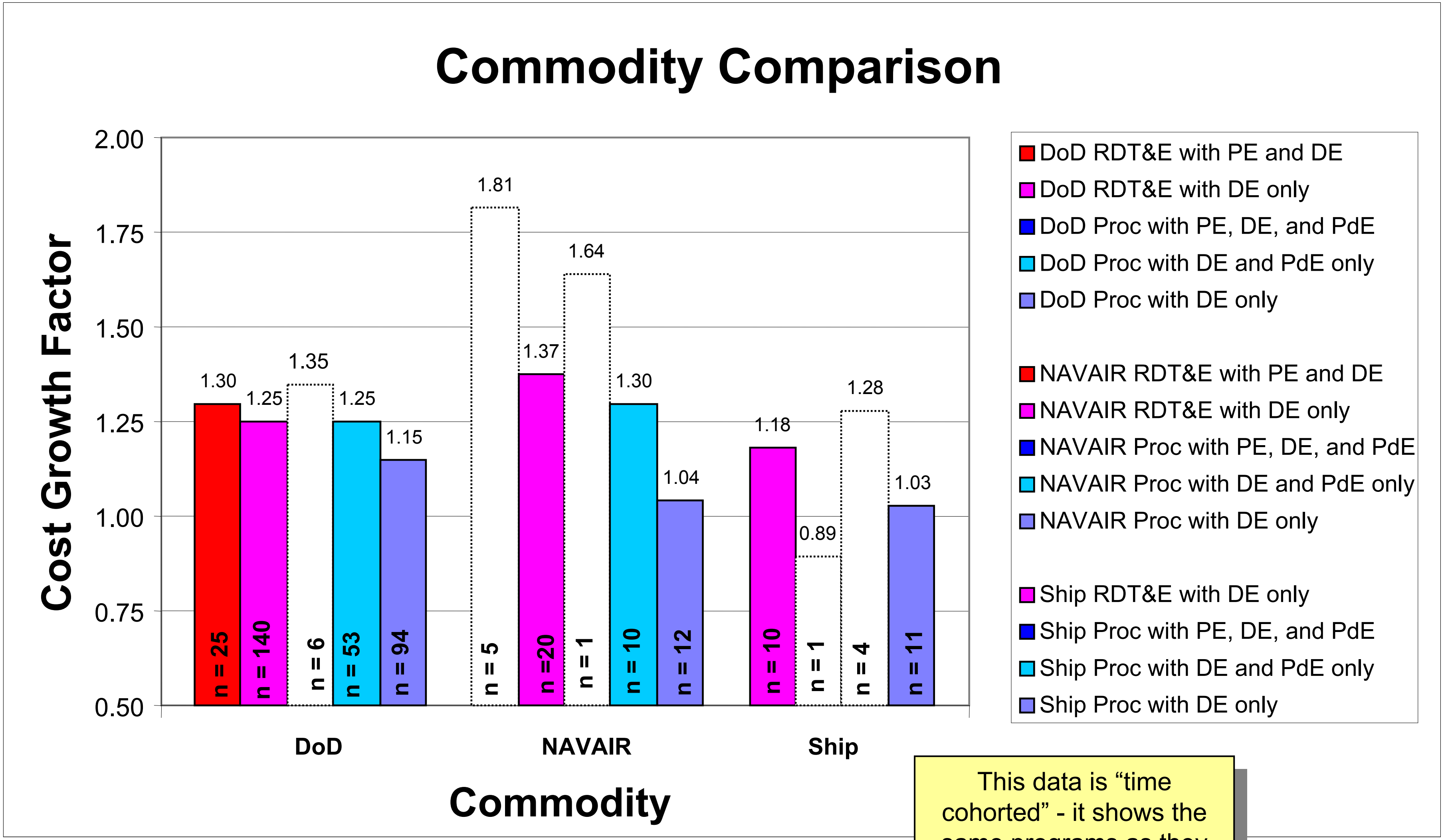
This data is "time cohorted" - it shows the same programs as they progress

DoD Procurement Cost Growth



This data is "time cohorted" - it shows the same programs as they progress

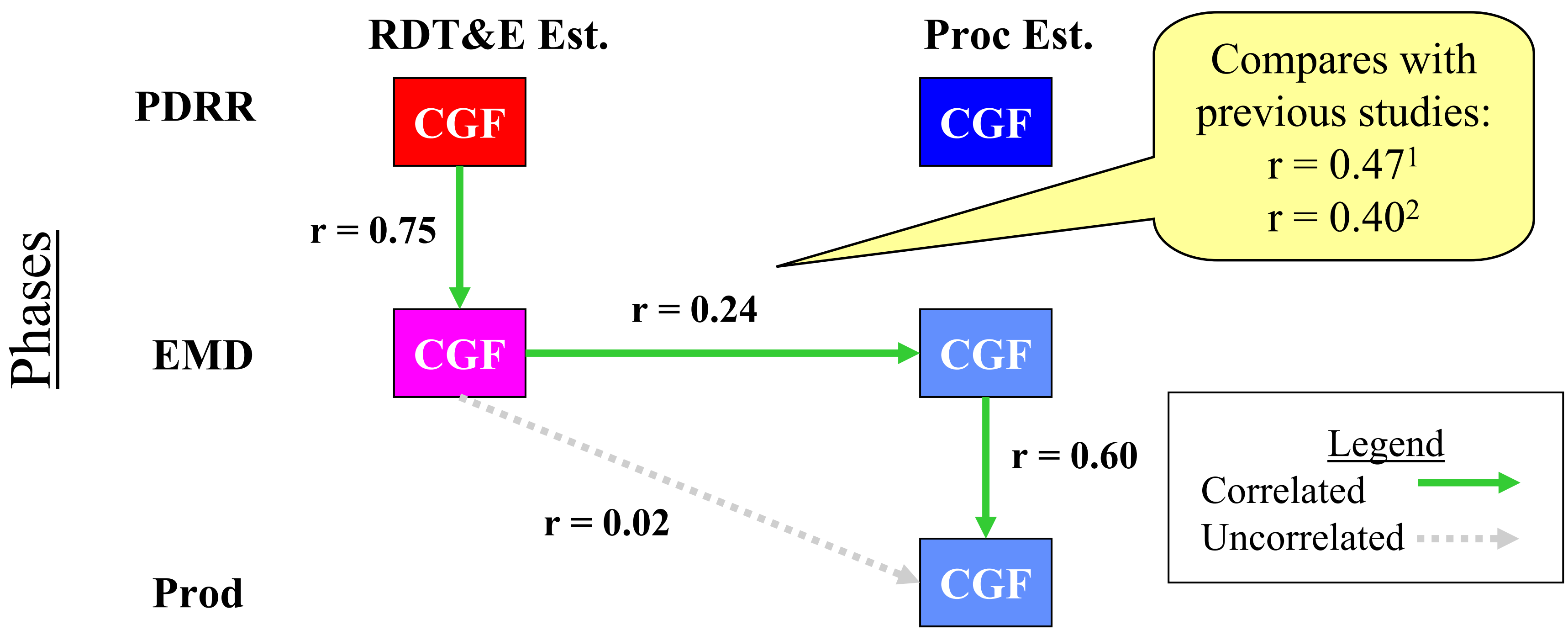
RAND Commodity Comparison – *Sufficient n only*



This data is "time cohorted" - it shows the same programs as they progress

Correlation

Appropriations



Note: There were many areas where there were too few data points to feel sure, only those with sufficient data to conclude the presence of correlation are indicated

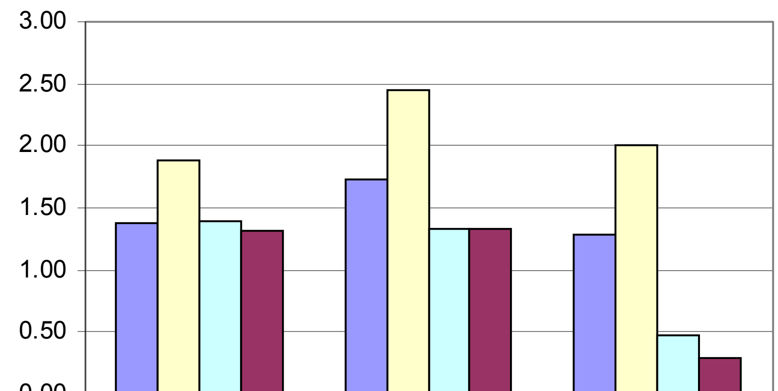
1. *Weapon System Cost Growth As a Function of Maturity,* DoDCAS 1996, **K. J. Allison, R. L. Coleman**
2. *Cost Risk Estimates Incorporating Functional Correlation, Acquisition Phase Relationships, and Realized Risk,* SCEA National Conference 1997, **R. L. Coleman, S. S. Gupta, J. R. Summerville, G. E. Hartigan**

This data is "time cohorted" - it shows the same programs as they progress

RAND 93 NAVAIR Commodities[1]

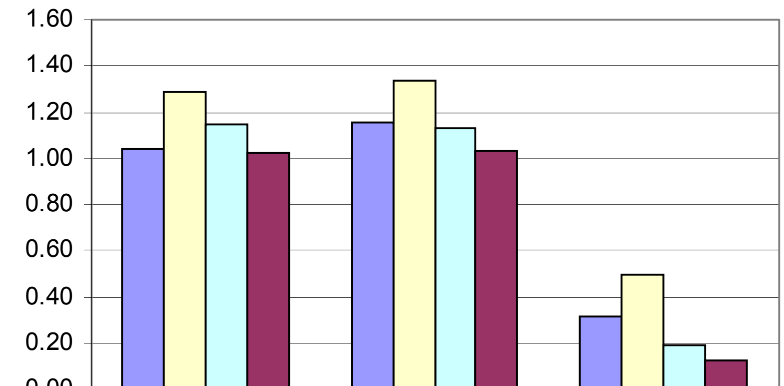
(Missiles, Electronics, Aircraft)

Cost Growth by Commodity
RAND 93 RDT&E



	Wgt Mean	Raw Mean	Std Dev
All n=20	1.37	1.72	1.28
Missile n=7	1.88	2.45	2.00
Elec n=6	1.39	1.33	0.47
A/C n=7	1.32	1.34	0.29

Cost Growth by Commodity
RAND 93 Procurement



	Wgt Mean	Raw Mean	Std Dev
All n=12	1.04	1.15	0.31
Missile n=4	1.29	1.33	0.49
Elec n=2	1.15	1.13	0.19
A/C n=6	1.02	1.03	0.13

- Missiles incur the most growth for both RDT&E and Procurement
- In Procurement, Electronics are second with Aircraft incurring almost no growth
- In RDT&E, Aircraft and Electronics are about equal

Notes: 1. Much of this difference is likely due to size, not commodity
2. Data from RAND 93 Navair DE only cohorts (only cohort group with enough data to break down by commodity)
3. This is descriptive analysis only. Inferential statistics not useable due to small n.

Cost Risk

Cost Risk Models

Basic Flow of a Risk Process

Inputs

Structure & Execution
Includes the organization, the mathematical assumptions, and how the model runs

Outputs

From the cost analyst and technical experts
- The CARD
  - Or, System Description
- Expert rating/scoring
- Point Estimate

To the decision maker and the cost analyst
- Means
- Standard Deviations
- Distributions
- Risk by CWBS

Inputs and outputs, although outside the purview of the risk analyst, are determined by the structure and execution of the risk model

General Model Architecture

Inputs

Scoring
- Interval w/ objective criteria
- Interval
- Ordinal
- None

Dollar Basis
- Historical
- Domain Experts
- Conceptual

Structure

Organization
- Coverage & Partition
  - Cost Estimating
  - Schedule / Technical
  - Requirements
  - Threat
- Assigning Cost to Risk
  - CERs
  - Direct Assessment of Distribution Parameters
  - Factors
  - Rates
- Below-the-Line
  - Yes
  - No

Probability Model
- Distribution
  - Normal
  - Log Normal
  - Triangular
  - Beta
  - Bernoulli
- Correlation
  - Functional
  - Relational
  - Injected
  - None

Execution

Computation
- Monte Carlo
- Method of Moments
- Deterministic

Cross Checks
- Means
- CVs
- Inputs

Tip: Higher is better except in Cross Checks

Inputs – Scoring

- Interval
  - Set scoring for which the distance (interval) between scores has meaning
    - Low risk is assigned a 1, medium risk is assigned a 5, and a high risk is assigned a 10
    - Note that it is not immediately clear that the scale is interval, but it is surely not subject to objective criteria.
- Ordinal
  - Score is relative to the measurement
    - e.g., difficulty in achieving schedule is high, medium, or low
- None

SCORING	INPUTS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

Org – Assigning Cost to Risk

- Risk CERs: Equations developed to reflect the relationship between an interval risk score and the cost impact of the risk
  - These equations amount to the same thing as CERs used in the cost estimate – they map risk scores to risk percents or dollars
  - e.g., Risk Amount = 0.12 * Risk Score
- Direct Assessment of Distribution Parameters: Experts estimate parameters of the risk distribution
  - e.g. Low and high triangular endpoints assessed by domain experts
  - e.g. Shifted means assessed for Normals
  - Note: Scoring is completely eliminated from this method

SCORING	INPUTS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

Org – Assigning Cost to Risk

- Factors: Fractions or percents are used in conjunction with the scores and the cost of the component or program
  - e.g., a score of 2 increases the cost of the component by 8%
  - Antenna Risk Score = 2
  - Cost of Antenna = $4090K
  - Risk Amount = 0.08 * 4090K = $327.2K
- Rates: Predetermined costs are associated with the scores
  - e.g., a score of 2 has a cost of $100K
  - Antenna Risk Score = 2
  - Cost of Antenna = $4090K
  - Risk Amount = $100K

Warning: Rates are independent of the element's cost.

SCORING	INPUTS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

Probability Model – Correlation

Correlation is a measure of the relation between two or more variables/WBS elements

- Functional: Arises between source and derivative variables as a result of functional dependency. The lines of the Monte Carlo are cell-referenced wherever relationships are known.
  - CERs are entered as equations
  - Cell references are left in the spreadsheet
  - When the Monte Carlo runs, input variables fluctuate, and outputs of CERs reflect this
    - Thus, risk applied to independent variables flows down to dependent variables

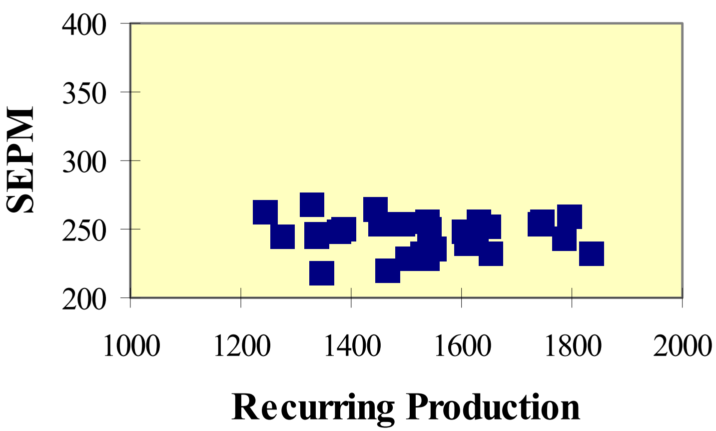
An Overview of Correlation and Functional Dependencies in Cost Risk and Uncertainty Analysis, R. L. Coleman and S. S. Gupta, DoDCAS, 1994

SCORING	INPUTS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

Functional Correlation Demonstration

No Functional Correlation

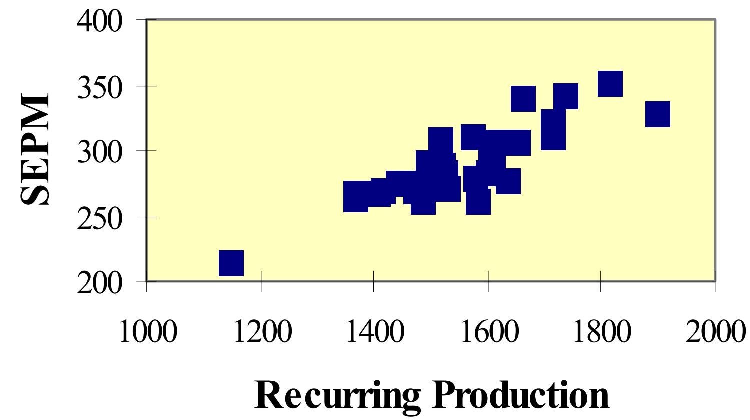
- Simulation run with WBS items entered as values



Not Correlated

With Functional Correlation

- Simulation run with functional dependencies



Correlated

Note shift of mean, and increased variability

Execution – Computation

- **Monte Carlo Simulation:** A widely accepted method, used on a broad range of risk assessments for many years. It produces cost <u>distributions</u> through the generation of random numbers. The cost distributions give decision makers insight into the range of possible costs and their associated probabilities.
- **Method of Moments:** The mean and standard deviation of lower-level WBS lines are known, and are rolled up assuming independence to provide higher-level distributions
  - Only provides an analysis of distribution at a top level
  - Easy to calculate
  - Negated by the rapid advances in microcomputer technology
  - Only works for independent elements, unless covariances are allowed for, which is difficult
- **Deterministic:** Only point values are used. No shifts or other probabilistic effects are taken into account.

SCORING	INPUTS
ORGANI-ZATION	PROB. MODEL
COMPU-TATION	CROSS CHECKS

Cost Risk

Some Example Models

Types of Cost Risk Models

- Historical vs Expert-Opinion-Based
- Input vs Output
  - Input methods vary the input parameters or seek to define drivers, thus determining cost outputs
  - Output methods consider the range of costs without determining the ranges of parameters or drivers
- Hybrids
  - It is possible to combine Historical and Expert-Opinion-Based
  - It is not safe to combine input and output

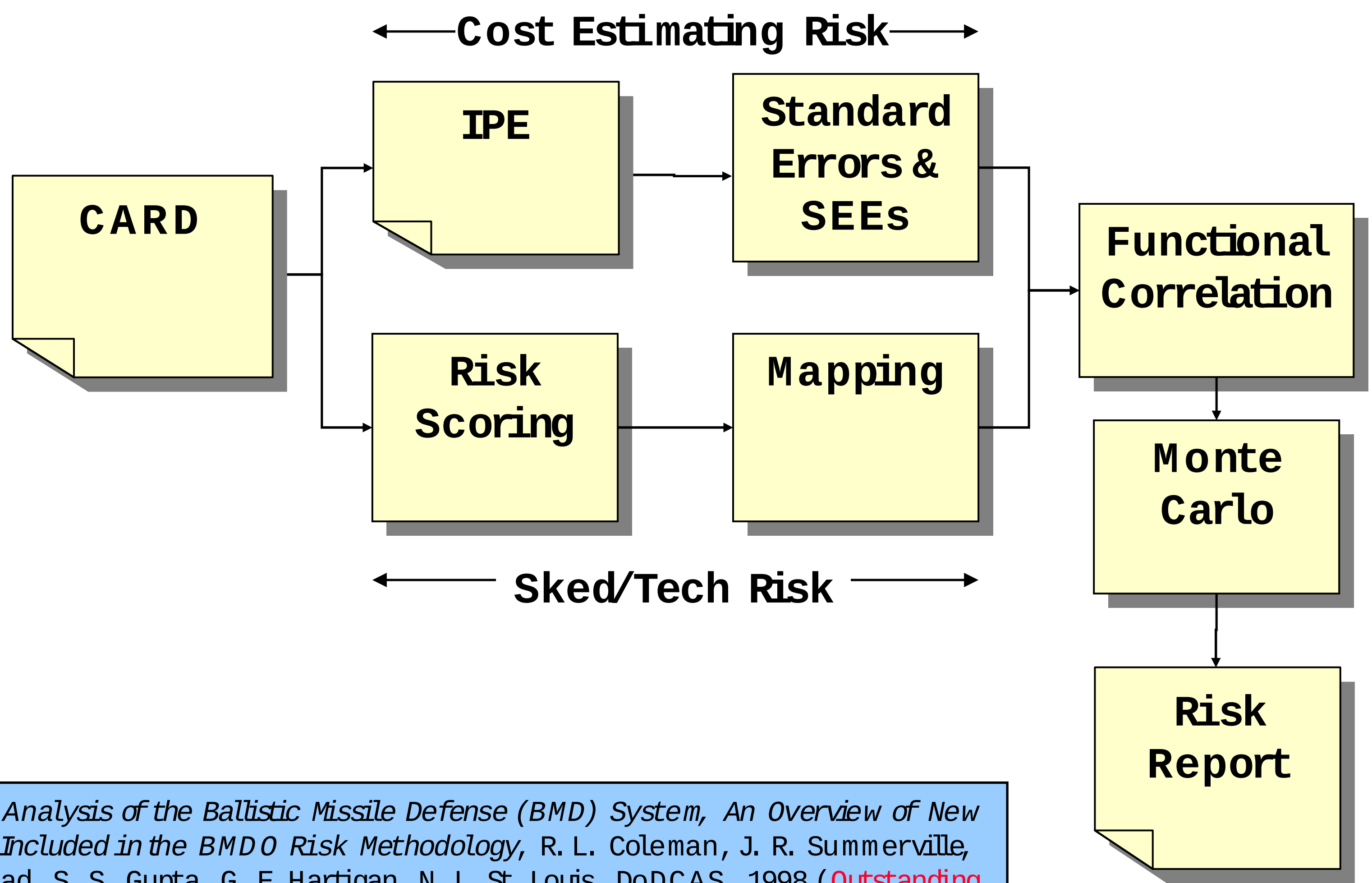
Cost Risk

Historical Cost Risk Methods

Used by
MDA
IC CAIG
and others

A Specific Historical Model

An Output Method



Cost Risk Analysis of the Ballistic Missile Defense (BMD) System, An Overview of New Initiatives Included in the BMDO Risk Methodology, R. L. Coleman, J. R. Summerville, D. M. Snead, S. S. Gupta, G. E. Hartigan, N. L. St. Louis, DoDCAS, 1998 (Outstanding Contributed Paper), and ISPA/SCEA International Conference, 1998

General Model Architecture

A Typical Historical Cost Risk Model

Inputs

Scoring

- ***Interval w/ objective criteria***
- Interval
- Ordinal
- None

Dollar Basis

- ***Historical***
- Domain Experts
- Conceptual

Structure

Organization

- Coverage & Partition
  - ***Cost Estimating***
  - ***Schedule / Technical***
  - ***Requirements***
  - ***Threat***
- Assigning Cost to Risk
  - ***CERs***
  - Direct Assessment of Distribution Parameters
  - Factors
  - Rates
- Below-the-Line
  - ***Yes***
  - **No**

Probability Model

- Distribution
  - ***Normal***
  - Log Normal
  - Triangular
  - Beta
  - Other (e.g., Bernoulli)
- Correlation
  - ***Functional***
  - Injected historical
  - Relational
  - Injected nominal
  - None

Execution

Compu-tation

- ***Monte Carlo***
- Method of Moments
- Deterministic

Cross Checks

- *Means*
- *CVs*
- *Inputs*

Historical Model

Risk Scoring and Mapping

- Technical experts score the schedule/technical risk to the program using a set of objective matrices
  - Scores range from 0 (no risk) to 10 (high risk)
- Weighted average risk scores are mapped to a cost growth distribution
  - Distribution is based on a database of cost growth factors of major weapon systems collected from SARs
    - Programs range from those which experienced tremendous cost growth due to technical problems to those which were well managed and under budget

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Historical Model

Hardware scoring matrix

Risk Categories	Risk Scores (0=Low, 5=Medium, 10=High)				
	0	1-2	3-5	6-8	9-10
1 Technology Advancement	Completed (State of the Art)	Minimum Advancement Required	Modest Advancement Required	Significant Advancement Required	New Technology
2 Engineering Development	Completed (Fully Tested)	Prototype	HW/SW Development	Detailed Design	Concept Defined
3 Reliability	Historically High for Same Item	Historically High on Similar Items	Known Modest Problems	Known Serious Problems	Unknown
4 Producibility	Production & Yield Shown on Same Item	Production & Yield Shown on Similar Items	Production & Yield Feasible	Production Feasible & Yield Problems	No Known Production Experience
5 Alternate Item	Exists or Availability on Other Items Not Important	Exists or Availability of Other Items Somewhat Important	Potential Alternative Under Development	Potential Alternative in Design	Alternative Does Not Exist & is Required
6 Schedule	Easily Achievable	Achievable	Somewhat Challenging	Challenging	Very Challenging

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Historical Model

Software scoring matrix

Risk Categories	Risk Scores (0=Low, 5=Medium, 10=High)				
	0	1-2	3-5	6-8	9-10
Requirements Definition	A-Spec fully documented and vetted w/users and mapped to CSCIs	Draft Requirements Document not through final vetting -initial CSCI mapping	Draft Requirements Document at total program level (vice SW CSCI)	Requirements Document in development	No Requirements Document other than the ORD
Interface Requirements (custom application)	Stand-alone system	Well defined/mature industry standard interfaces	Interfaces relatively new and subject to minor changes	Interfaces defined in parallel with software development effort	Interfaces designed individually
COTS Integration	No COTS software integration required	Limited number of COTS packages (less than 5) with established integration protocols (e.g., CORBA) - very stable products -loose coupling	Moderate use of COTS packages with moderate integration/ coupling	Highly specialized COTS packages in beta release used with no established integration protocols and tight coupling	Modifications to "COTS" code required to accommodate integration
User Interaction	No interaction with software	Limited number of users and limited interaction	Moderate number of users and moderate interaction	Significant number of users and significant interaction	Significant number of users and significant interaction and multiple services
Resource Availability	Plentiful	Resources required with general purpose skills and collateral/secret clearance	Moderate shortages of personnel with required skills experienced -Moderate turnover	Personnel with requisite skills in high demand – significant shortages in personnel experienced/expected and top secret clearance -Significant turnover	Resources required with highly specialized skills (low supply) and stringent security requirements (SCI and above)
% Complete	95%-100% Complete	75%-95% Complete	45%-75% Complete	15%-45% Complete	0-15% Complete

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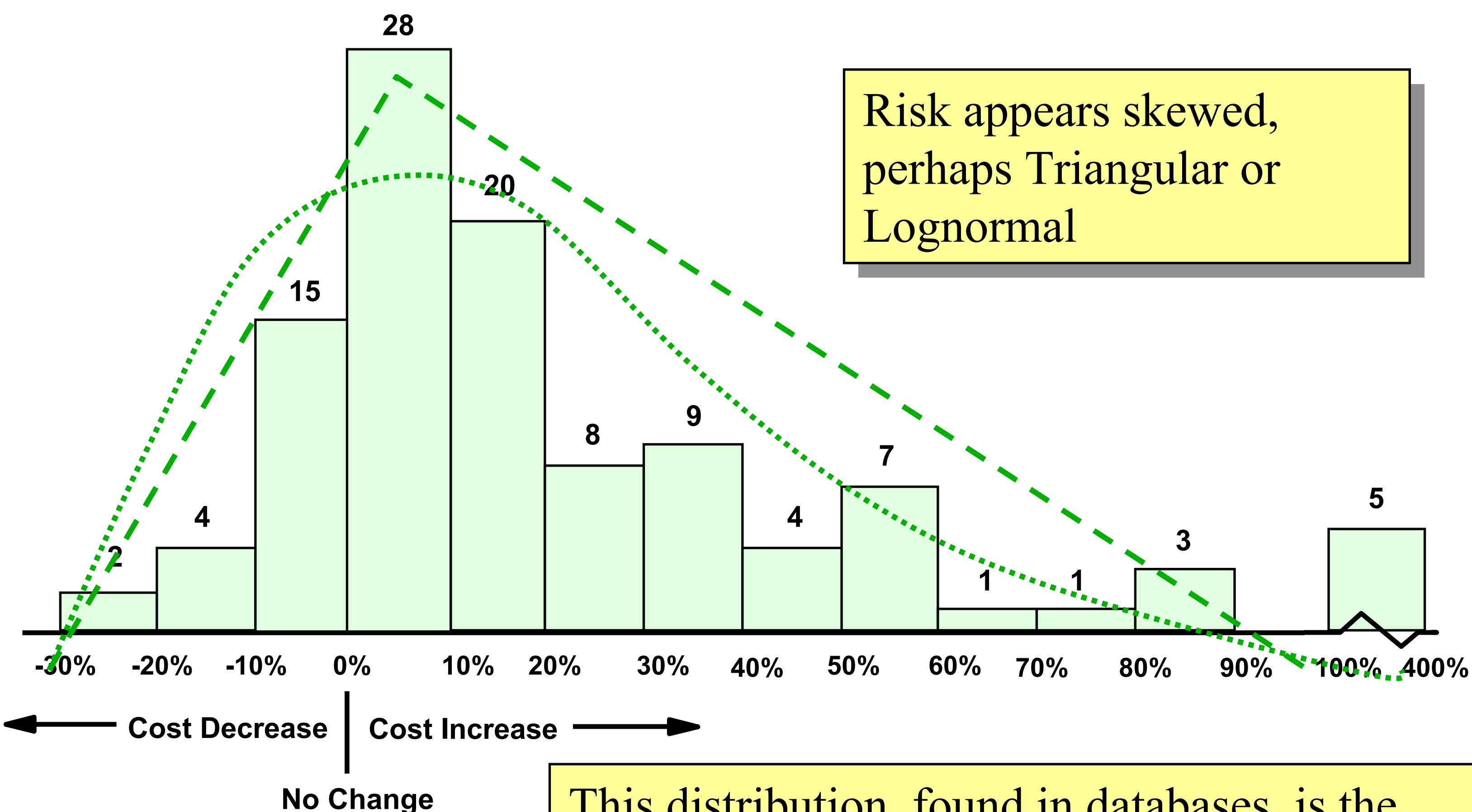
Cost Growth Database

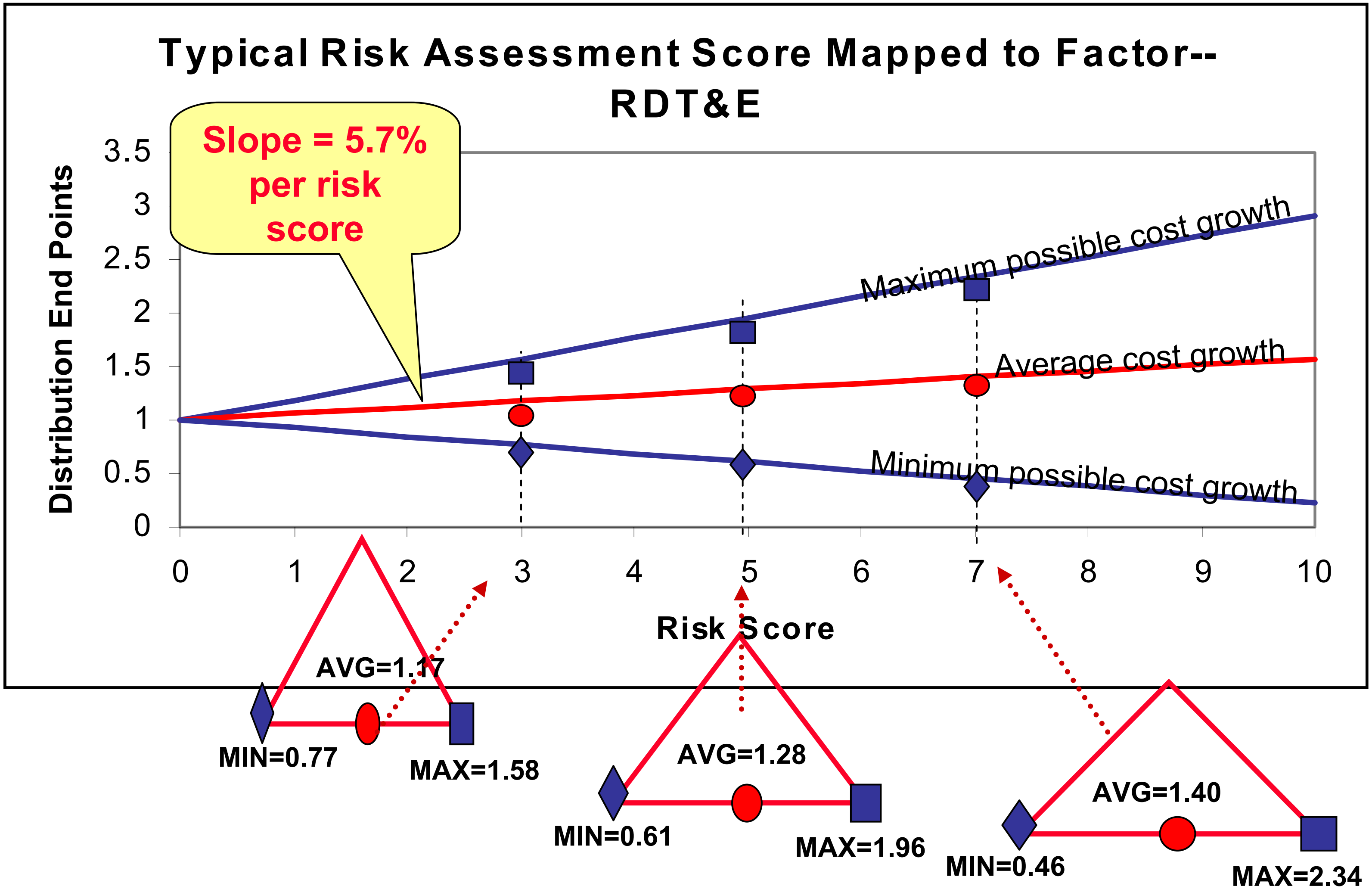


Risk appears skewed, perhaps Triangular or Lognormal

This distribution, found in databases, is the result of a blending of a family of distributions as shown on the next slide.

Historical Model

Sked/Tech mapping equations



Note: This slope is for typical H/W-intensive programs

Historical Model

Correlation

- Correlation can have a significant impact on risk analyses
  - Increases variability … easily doubling it … this affects confidence intervals and percentiles
  - Adds risk to "Below-the-line" costs like SE/PM and the like
    - It is often the only way to get any idea of these impacts
- Correlation in historical models is generally best handled using functional correlation

Cost Risk

Expert Opinion Methods

Used by
NGA
and others

General Model Architecture

A Typical Expert-Opinion-Based Cost Risk Model

Inputs

Scoring
- Interval w/ objective criteria
- Interval
- Ordinal
- ***None***

Dollar Basis
- Historical
- ***Domain Experts***
- Conceptual

Structure

Organization
- Coverage & Partition
  - ***Cost Estimating***
  - ***Schedule / Technical***
  - ***Requirements***
  - ***Threat***
- Assigning Cost to Risk
  - CERs
  - ***Direct Assessment of Distribution Parameters***
  - *Factors*
  - Rates
- Below-the-Line
  - ***Yes***
  - **No**

Probability Model
- Distribution
  - Normal
  - Log Normal
  - *Triangular*
  - Beta
  - Other (e.g., Bernoulli)
- Correlation
  - *Functional*
  - Injected historical
  - Relational
  - Injected nominal
  - None

Execution

Compu-tation
- ***Monte Carlo***
- Method of Moments
- **Deterministic**

Cross Checks
- *Means*
- *CVs*
- *Inputs*

A Specific Expert-Based Method

An Output Method

- Adapted Software Engineering Institute's (SEI) Software Risk Evaluation Method
  - Tailored to address the hardware, software, and organization-unique aspects of the program
  - Includes Identification, Quantification, and Mitigation
- Employed SEI Taxonomy
  - Systematic way of eliciting and organizing risks
  - Consistent framework for the development of risk management methods and techniques
  - 3 major classes:
    - Product Engineering
    - Development Environment
    - Program Constraints
- Added quantification step based on current hardware risk practice
- Methodology used in two risk analyses to date

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Sample SEI Questionnaire

PRODUCT ENGINEERING

Requirements

Stability

Are requirements changing even as the system is being produced?

1. Are the external (Current and new) interfaces changing?

Clarity

Are the requirements unclear or in need of interpretation?

2. Does everyone responsible for the development/acquisition of the program have a clear understanding of the program requirements?

Validity

Will the requirements lead to the system the customer has in mind?

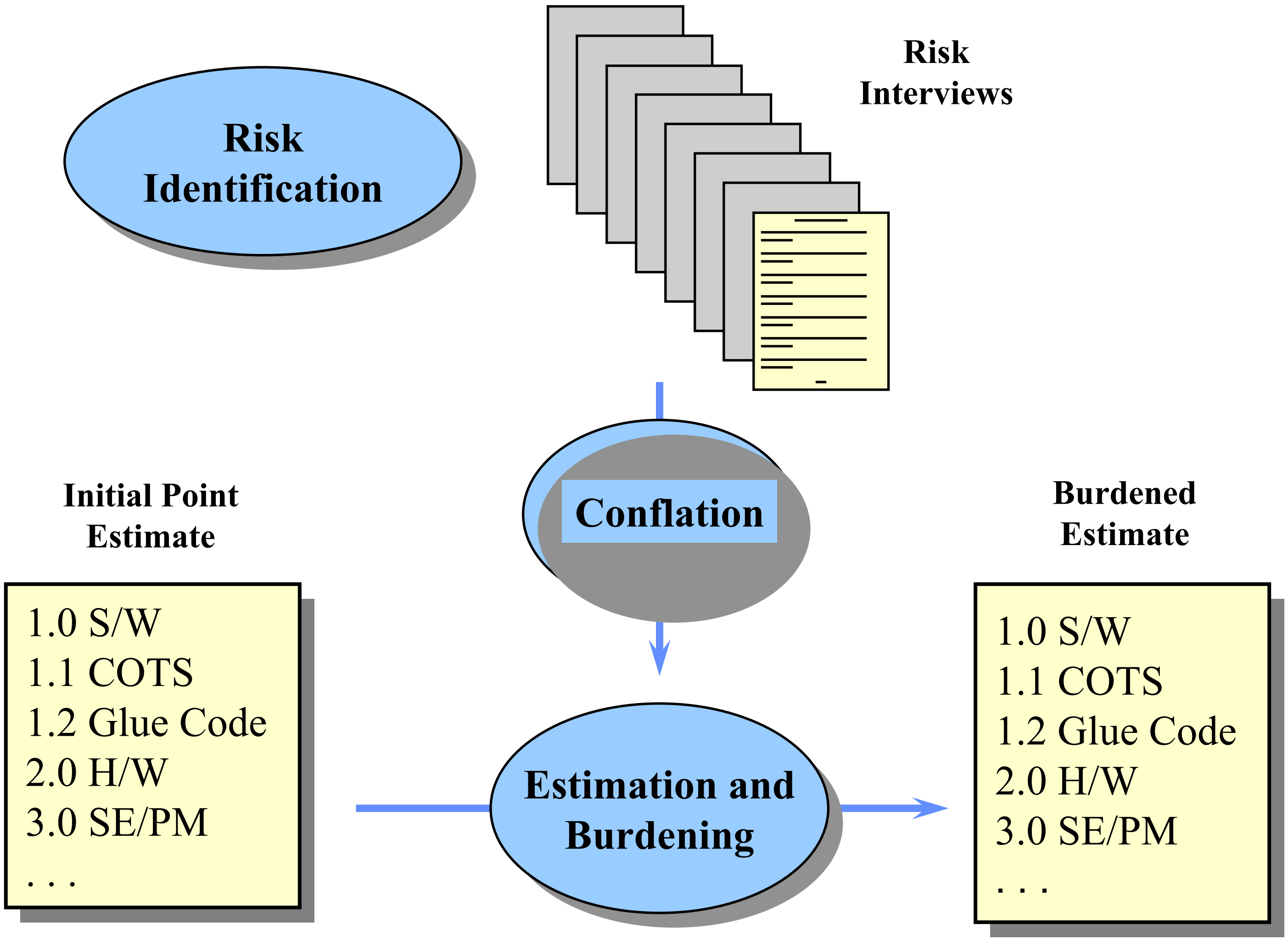
3. Do the program office, the development contractor, NIMA management and the customer understand the same thing by the requirements?

e. Feasibility

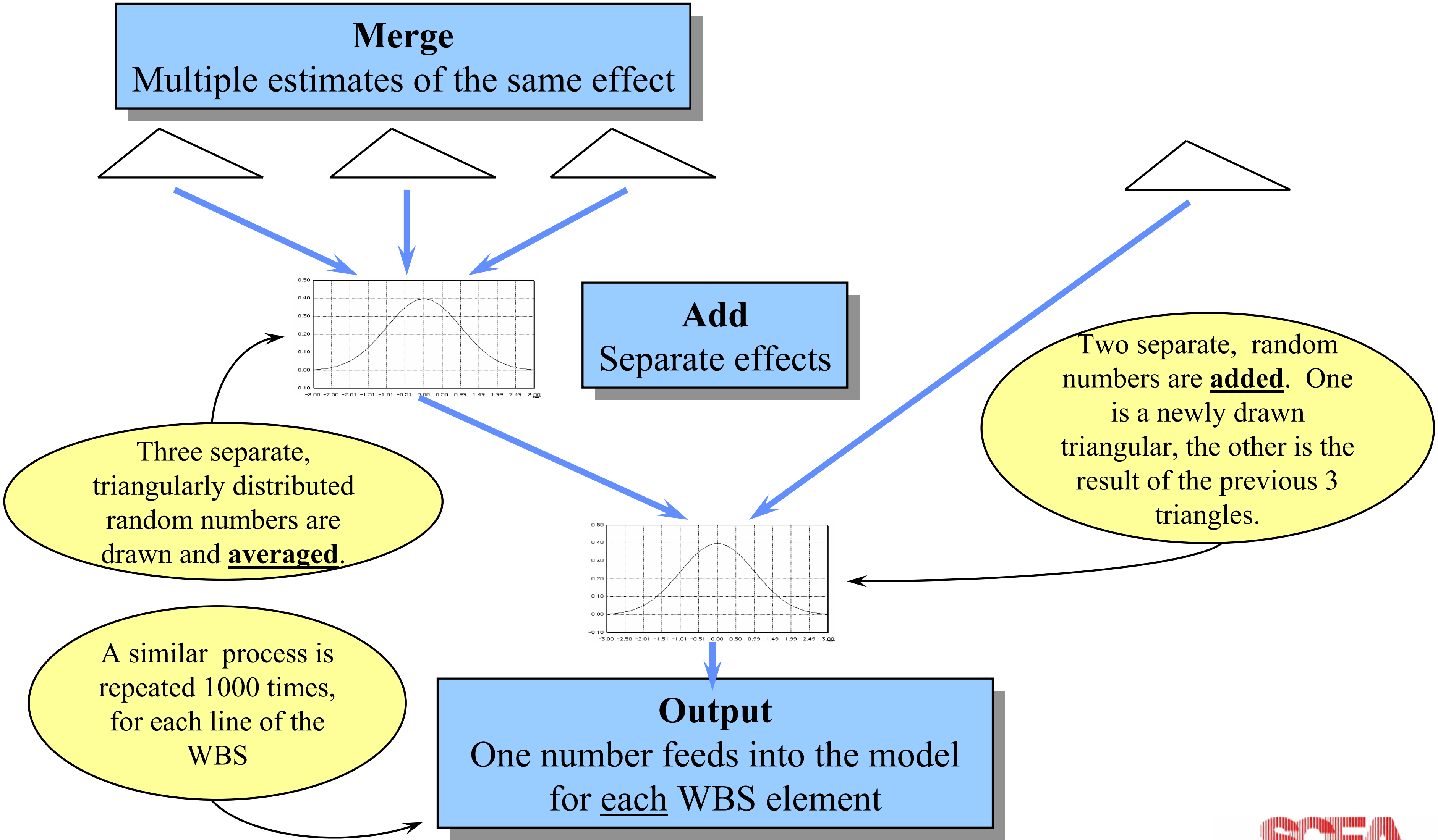
Are requirements infeasible from an analytical point of view?

4. Are there any requirements that are technically difficult to implement?
   (Yes) What are they?
   (Yes) Why are they difficult to implement?

Risk Model Process



Conflation of Expert Interviews



Estimation and Burdening

Steps:

Take the base Number → Multiply by a random variable resulting from the conflation process → Collect the results in a histogram

Example:

WBS	Initial Point Estimate	Conflation Result	Burdened Result
1.0 S/W	100M		148M
1.1 COTS	80M	1.1	88M
1.2 Glue Code	20M	3.0	60M
2.0 H/W	10M	1.2	12M
3.0 SE/PM	11M		16M
Total	121M		176M

Some elements are roll-ups

Some elements are factors off of others

The result is a burdened estimate

Products & Timeline

Tailored Risk Taxonomy Questionnaire

Delivery date: Start + 5 days

Includes:
- Subject-specific questions
- Tailored question sets

Risk Model

Delivery date: Start + 80 days

Includes:
- Risk expected values
- Risk distributions

Risk Report

Delivery date: Model + 10 Days

Includes:
- Risk questionnaire
- Risk issue descriptions
- Risk WBS quantification

Risk Management

The Risk Cube Method

Used by

NGA

NRO

MDA

DD(X)

NAVAIR

and others

Engineers' and Cost Analysts' Views of Risk

Engineers	Cost Analysts
• Work in physical materials, with – Physics-based causal responses – Physical connections	• Work in dollars and parameters, with – Statistical relationships – Correlation
• Typically examine or discuss a specific, discrete outcome – Point designs – Specific system parameters such as weight, size	• Typically examine or discuss a general, continuous outcome set – Probability distributions – Statistical parameters such as mean and standard deviation
• Typically seek to know: – Given this solution, what will go wrong? – Are design margins enough?	• Typically seek to know: – Given this relationship, what is the range of possibilities? – Are cost margins enough?
• Usually prefer risk management methods	• Usually prefer cost risk methods

Both views are valid. The goal is to merge the best qualities of both views.

Risk Cube Method

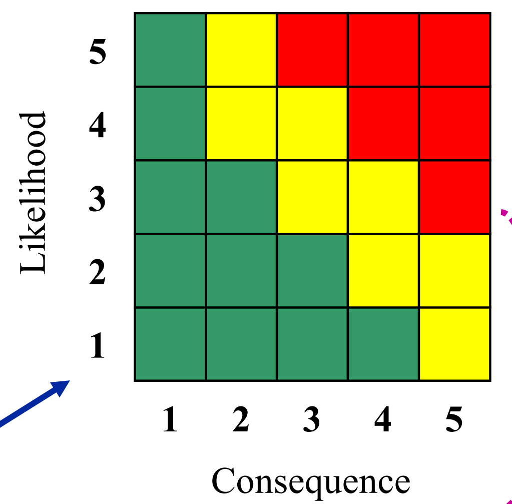
Note: Generic Risk Cube

Likelihood

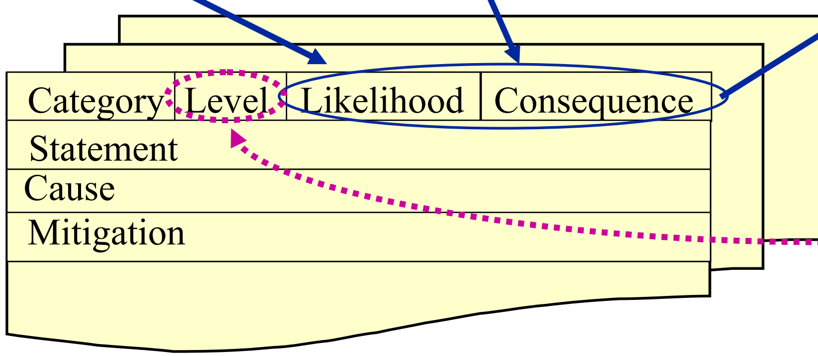
Level	Likelihood
1	Not Likely
2	Low Likelihood
3	Likely
4	Highly Likely
5	Near Certainty

Consequence

Level	Technical	Schedule	Cost
1	Minimal or no impact	Minimal or no impact	Minimal or no impact
2	Minor technical shortfall	**Slip < _*_ month(s)**	**< (1% of Budget)**
3	Moderate technical shortfall	**Slip < _*_ month(s) of critical path. Sub-system slip > _*_ month(s).**	**< (5% of Budget)**
4	Unacceptable, workarounds available	**Slip < _*_ months**	**< (10% of Budget)**
5	Unacceptable, no alternative exist	Cannot achieve key program milestones	**> (10% of Budget)**



Risk Item Assessments:



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General Model Architecture

The Risk Cube Approach to Risk Management

Inputs

Scoring

- Interval w/ objective criteria
- ***Interval***
- ***Ordinal***
- None

Dollar Basis

- Historical
- ***Domain Experts***
- Conceptual

Structure

Organization

- Coverage & Partition
  - Cost Estimating
  - ***Schedule / Technical***
  - Requirements
  - Threat
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Execution

Compu-tation

- ***Monte Carlo***
- Method of Moments
- ***Deterministic***

Cross Checks

- Means
- CVs
- Inputs

Risk Cube Assessment Process

Steps:

1. Convert risk scoring to Probabilities and Consequence percents
2. Map risk items to CWBS
3. Setup Monte Carlo Simulation (using Bernoulli distributions) combining CWBS cost estimate with risk impacts
4. Run model and assess results (i.e., determine biggest hitters, look for potential errors, etc)
5. Crosscheck results with historical data (based on program size)

Level of Effort Needed:

- A few days for preparation and familiarization of the team
- A day or two for mapping of risk items to the WBS
- Completion approximately one week after risk items are mapped to the WBS

The Risk Cube Method

- Outcome oriented - begins with analysis of all factors that can cause designs to fail or be wrong, by Subject Matter Experts (engineers), who:
  - Identify each factor (risk item)
  - For each item, estimate the probability of occurrence (Pf) and the cost impact if it occurs (Cf)
- Can be represented by Bernoulli Random Variables
  - The expected cost overrun is the sum of cost impacts multiplied by their respective probabilities

$$Cost\ Risk = \Sigma\ Pf * Cf$$

$$Mean = Pf*Cf$$

$$Std\ Dev = Pf*(1\text{-}Pf)*Cf = Pf*Qf*Cf$$

- Relies on:
  - Complete lists of what could happen
  - Accurate Pf's and Cf's
  - Mapping of risk items to the WBS
- Pros:
  - Intuitive and Engineer/Designer-oriented outcome

Note: Qf = 1-Pf

Cons are on later slides →

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Standard Cf's

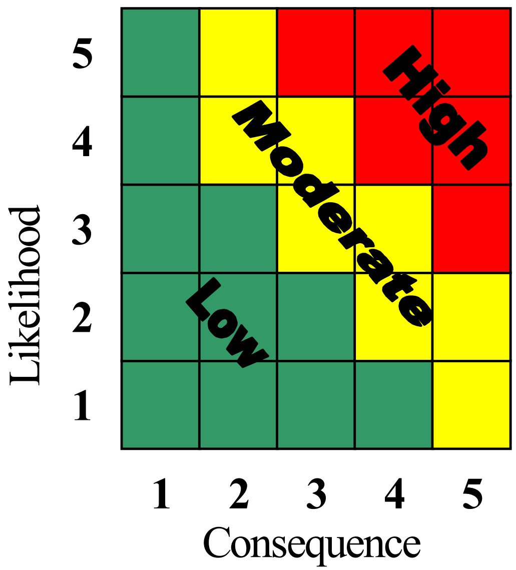
Consequence

Level	Technical (T)	Schedule (S)	Cost (C)
1	Minimal or no impact	Schedule slip to the scored area of $S \leq 10\%$	Cost increases to the scored area of $0\% < C \leq 15\%$
2	Minor technical shortfall, no impact to high level technical requirements	Schedule slip to the scored area of $10\% < S \leq 20\%$	Cost increases to the scored area of $15\% < C \leq 30\%$
3	Moderate technical shortfall but workaround available which will eliminate impact to high level technical requirements	Schedule slip to the scored area of $20\% < S \leq 30\%$	Cost increases to the scored area of $30\% < C \leq 45\%$
4	Unacceptable, workarounds available which will eliminate impact to high level technical requirement	Schedule slip to the scored area of $30\% < S \leq 40\%$	Cost increases to the scored area of $45\% < C \leq 60\%$
5	Unacceptable, no alternative exist	Schedule slip to the scored area of $40\% < S$	Cost increases to the scored area of $60\% < C$

Standard Pf's

Likelihood

Level	Probability (P)	Definition
1	$0.0 < P \leq 0.2$	Low likelihood
2	$0.2 < P \leq 0.4$	Low-to-medium likelihood
3	$0.4 < P \leq 0.6$	Medium
4	$0.6 < P \leq 0.8$	Medium-to-high likelihood
5	$0.8 < P \leq 1.0$	High likelihood



Setting up the Model

Per Risk Item

IPE	Uniform Draw	Cf * IPE	All Risk Items	IPE + Risk
IPE	Uniform Draw	Cf * IPE		IPE + Risk
IPE	Uniform Draw	Cf * IPE		IPE + Risk

<u>Total Cost</u> for each WBS Element from the Cost Estimate is used for the Initial Point Estimate.

A uniform distribution is used for the Crystal Ball assumption. Any value between 0 and 1 is equally likely.

If the draw is less than or equal to the Pf, then risk is applied to that WBS element. Risk dollars are calculated by multiplying the IPE and the Cf.

All the risk dollars are added to the IPE. This becomes the Crystal Ball forecast. Here we can see the risk distribution, mean IPE + Risk and other stats.

The Risk Cube vs. Historical

- Risk Cube methods can be adjusted to produce results that are comparable to historical cost growth
- However, the Risk Cube method cannot substitute for a historically based risk estimate
  - Unknown unknowns are not included
  - Small risks get omitted
  - SMEs tend to be biased or lack adequate familiarity with the program

Risk Cube vs. Historical

- Risk Cubes *do* add value
  - They are intuitive to engineers
  - Connect with risk management processes
- We expect Risk Cube results to be somewhat lower than historical
  - If only somewhat lower, the difference may be accounted for by unknown unknowns, small risks, and SME optimism
  - If much lower, be skeptical of the risk register
  - If higher, be alarmed … experts are rarely pessimistic

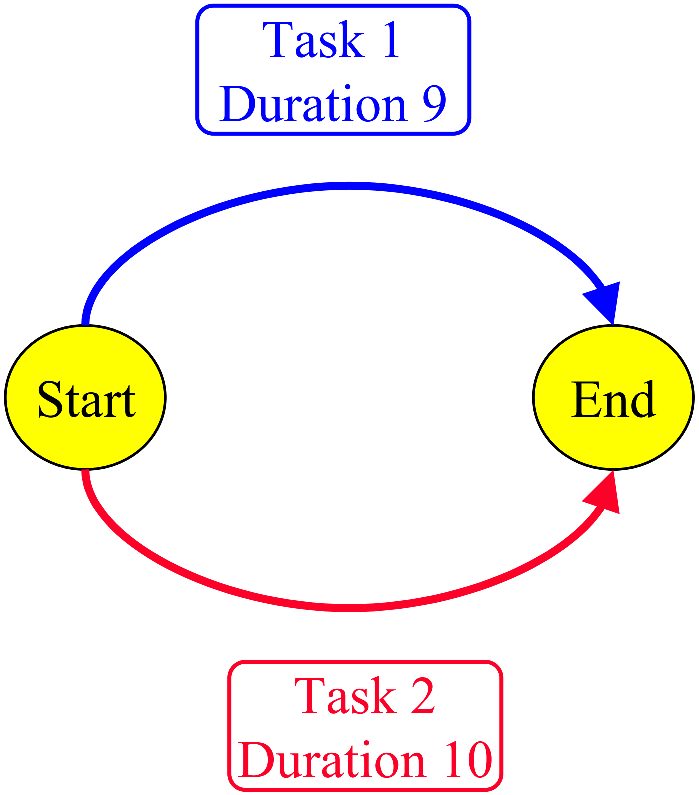
Schedule Risk

Schedule Risk

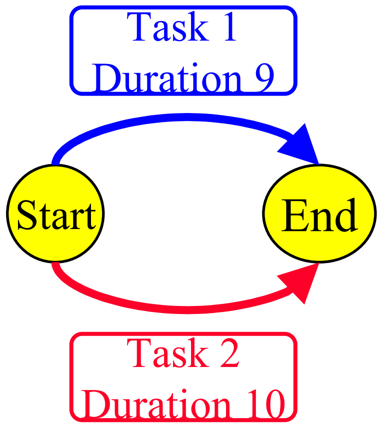
How Networks Operate - Some "Toy Problems"

Independent Tasks

- Tasks 1 and 2 begin at the same time and are independent
- Both tasks must be complete before the system is ready
- Duration is modeled as a uniform distribution ranging from Estimated ± 20%
  - Note that it is symmetric!
- What is the Expected Duration?



Independent Tasks



Each task is uniformly distributed from –20% to +20% of the expected duration

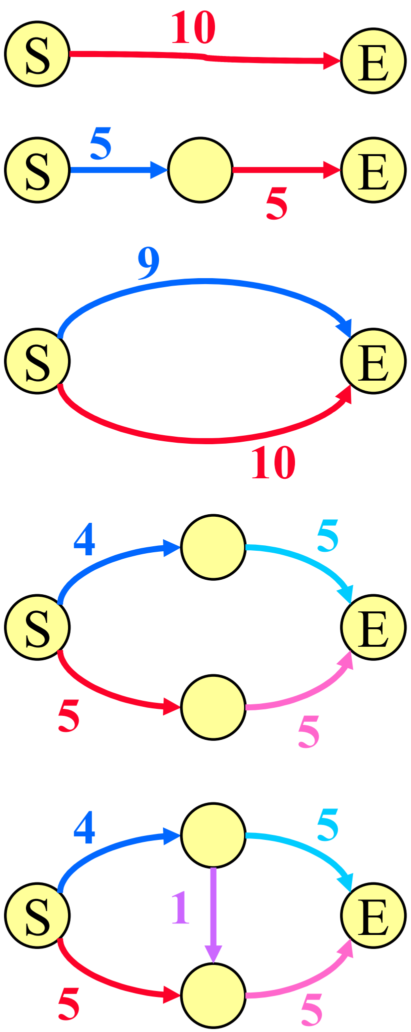
	Task 1	Task 2	Max Dur
	7.02	**11.91**	11.91
	7.08	**11.62**	11.62
	8.22	**11.27**	11.27
	10.00	**10.91**	10.91
	9.94	8.77	9.94
	9.03	**10.94**	10.94
	9.54	8.39	9.54
	10.05	**10.09**	10.09
	10.33	**11.22**	11.22
	10.59	**11.64**	11.64
Average	**9.18**	**10.68**	**10.91**
Criticality	**20%**	**80%**	

The "shorter" Task 1 is the critical path 20% of the time!

The average system duration is 10.91 months … longer than the estimated duration of either component task

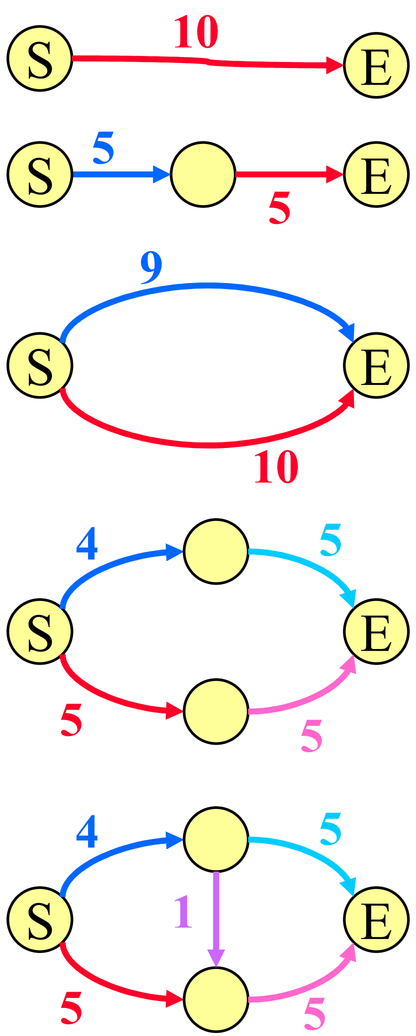
Comparisons with Constant Critical Path

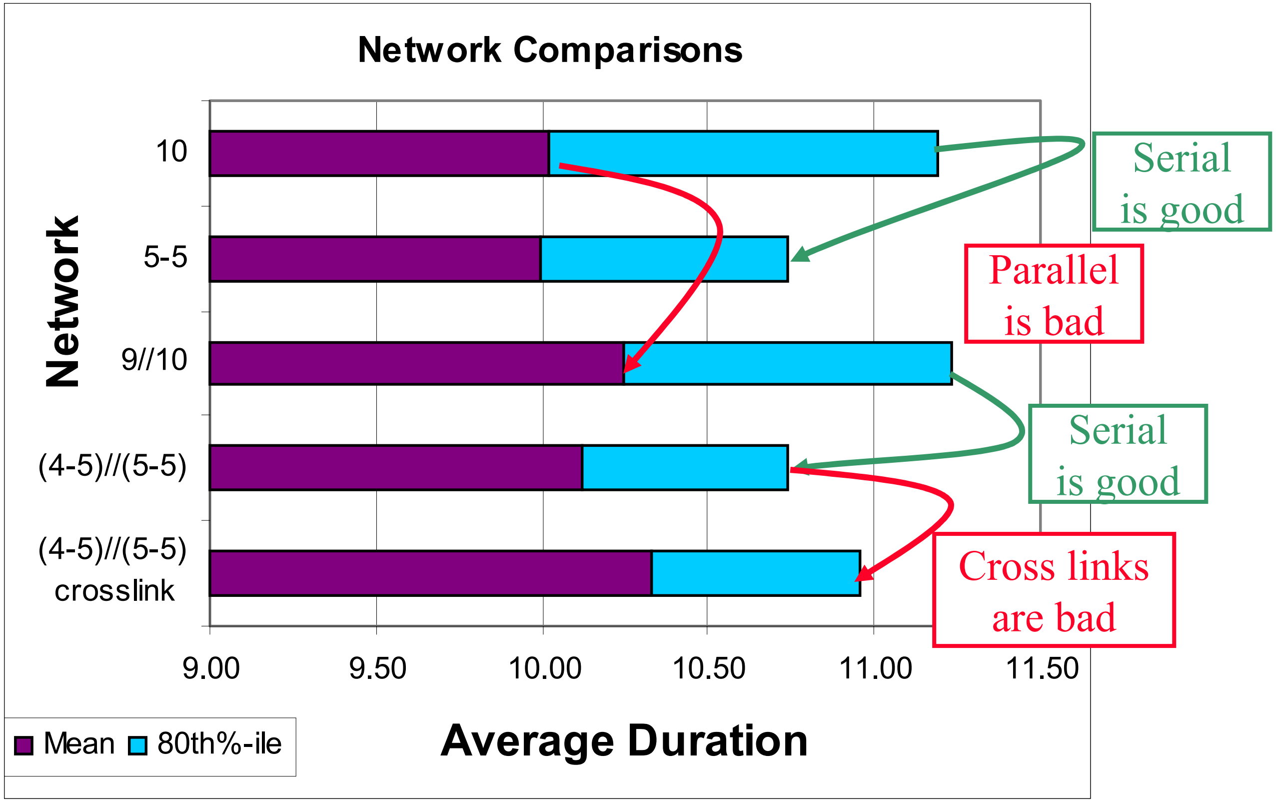
These all have Critical Path = 10



Comparisons with Constant CP

These all have CP = 10 … but their probabilistic durations are all different



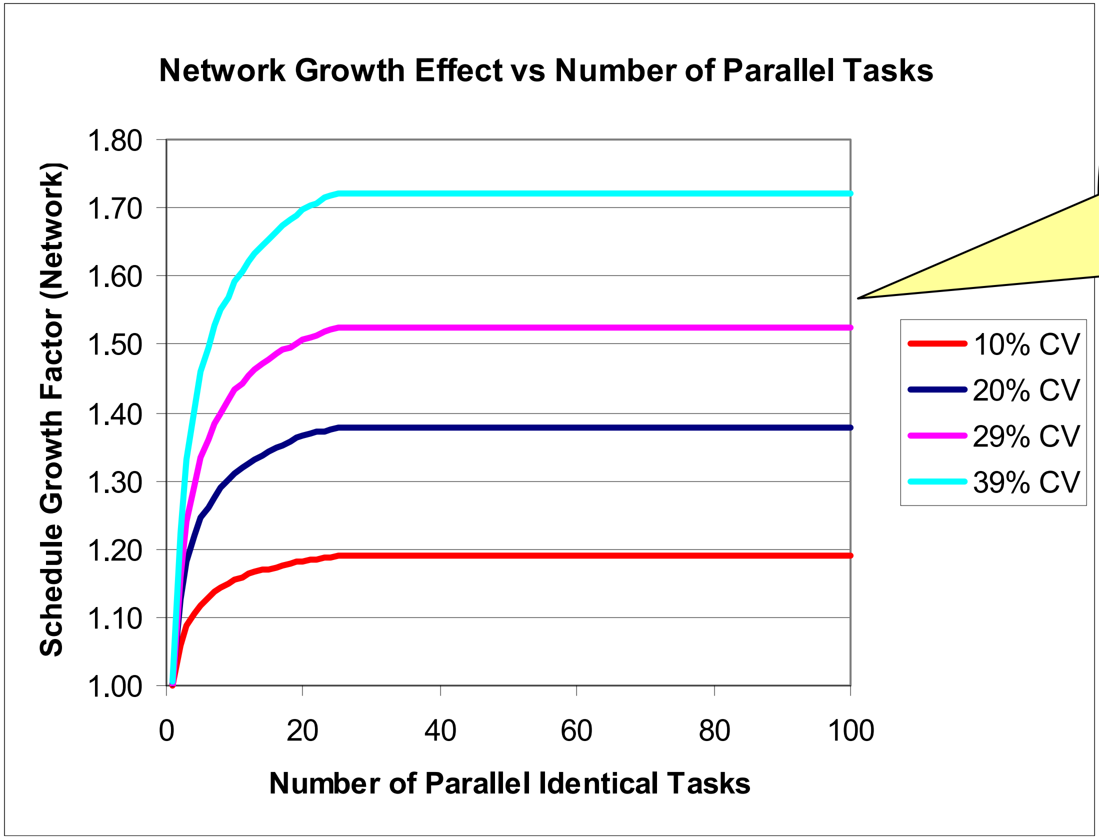


Durations were modeled as uniform distributions ranging from ±20% of the estimate. 5000 iterations were run.

Network Schedule Growth

As a Function of Network Complexity … Parallel-Task Toy Problem

- **This is another toy problem, to see what happens to a network as identical parallel tasks are added**

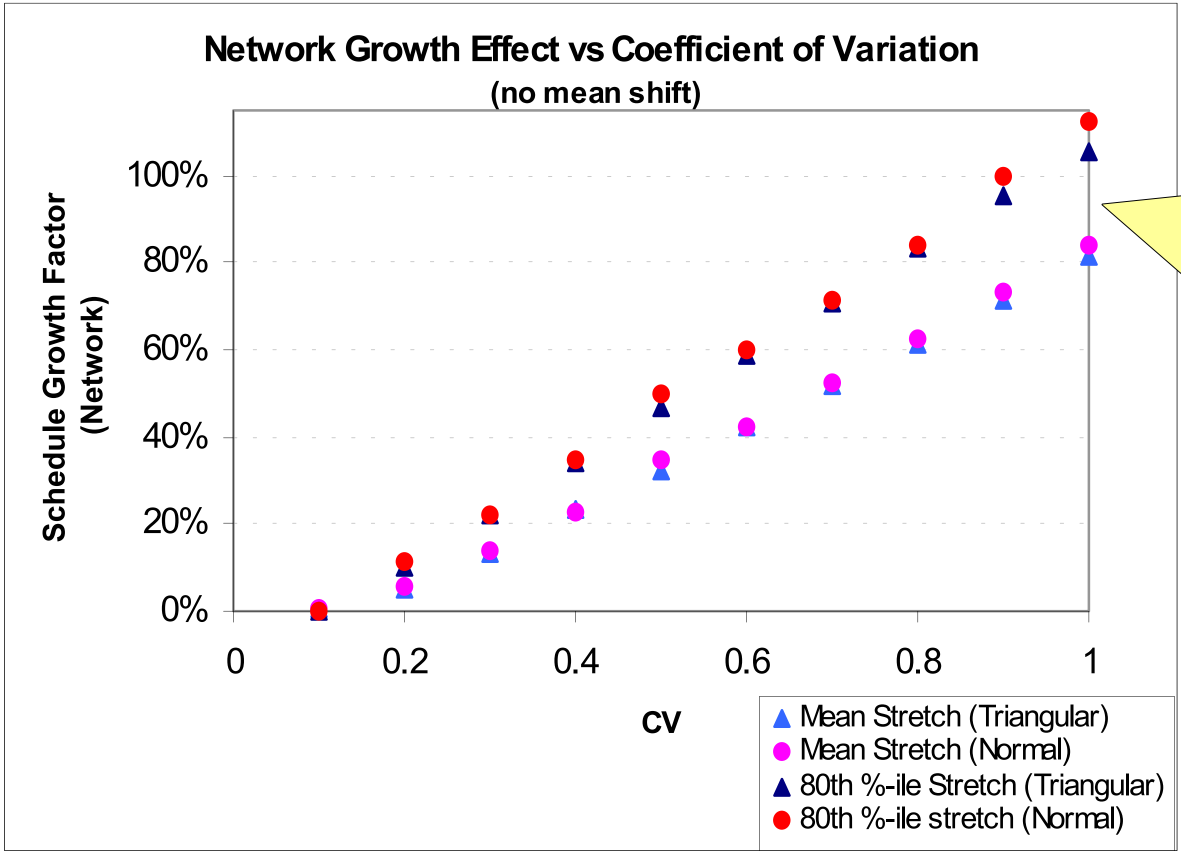


Increasing the number of tasks increases the schedule stretch

Network Schedule Growth

As a Function of Task Variance … Changing-CV Toy Problem

- This is a real network, with changing variance, to see what happens as variance grows



Increasing the variance of tasks increases the schedule stretch

"Toy Problem" Conclusions

- The duration of a network will be longer than any of the component legs
- Parallel tasks lengthen the average duration
  - Independent tasks that must finish at the same time should make you worry about schedule
  - The more parallel tasks, the more you stretch
- Serial tasks decrease the average duration
  - Serial tasks should make you feel a bit better about schedule
  - However, breaking a single task into smaller pieces will not improve your schedule
- Interdependencies (cross links) increase the average duration
  - Tasks that depend on two or more other tasks should make you worry about schedule
- Greater variability of the tasks will make the schedule duration grow

Schedule Risk

Schedule and Cost Growth[1]

Used at

FIA JMO

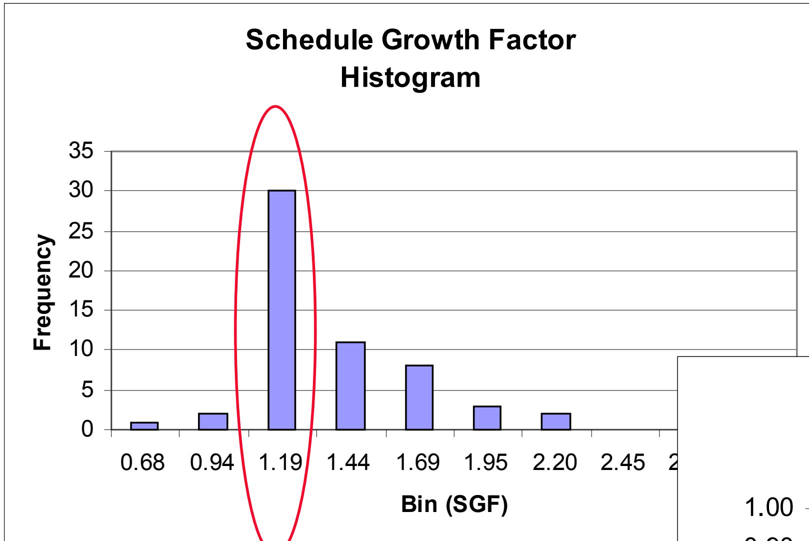
NGA

1. The Relationship Between Cost Growth and Schedule Growth, R. L. Coleman, J. R. Summerville, DoDCAS, SCEA 2002

The Data

- We analyzed data from the RAND Cost Growth Database with *both* the following characteristics:
  – Programs with E&MD only
    - Because growth is different for those with and without PDRR
  – Programs with schedule data in the requisite fields
- There were 59 points. The analysis follows.

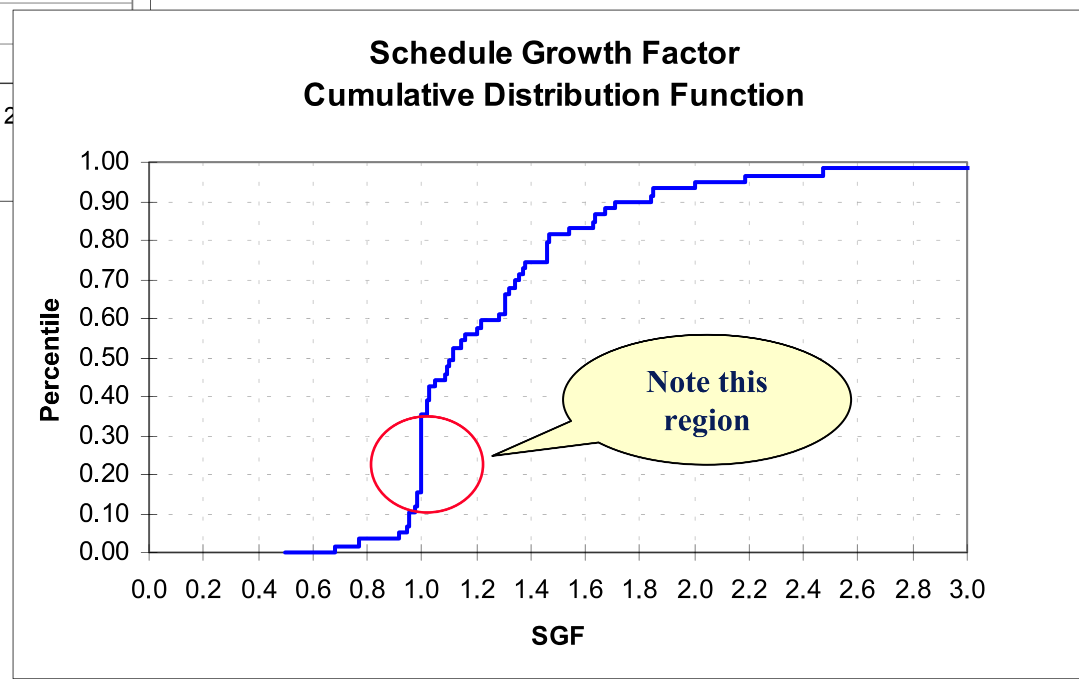
Schedule Growth Distribution



PDF for Schedule Growth

The distribution is highly skewed

CDF for Schedule Growth



These two graphs look much like CGF graphs, but the PDF is tighter here, and the CDF is steeper.

Basic Statistics of Schedule Change

• Mean		1.29
• Standard Deviation		0.54
• CV		42%
• 75th %-ile		1.46
• 61st %-ile		1.29
• 50th %-ile		1.11
• 25th %-ile		1.00
• Shrinkers	9/59	15.3%
• Steady	12/59	20.3%
• Stretchers	38/59	64.4%

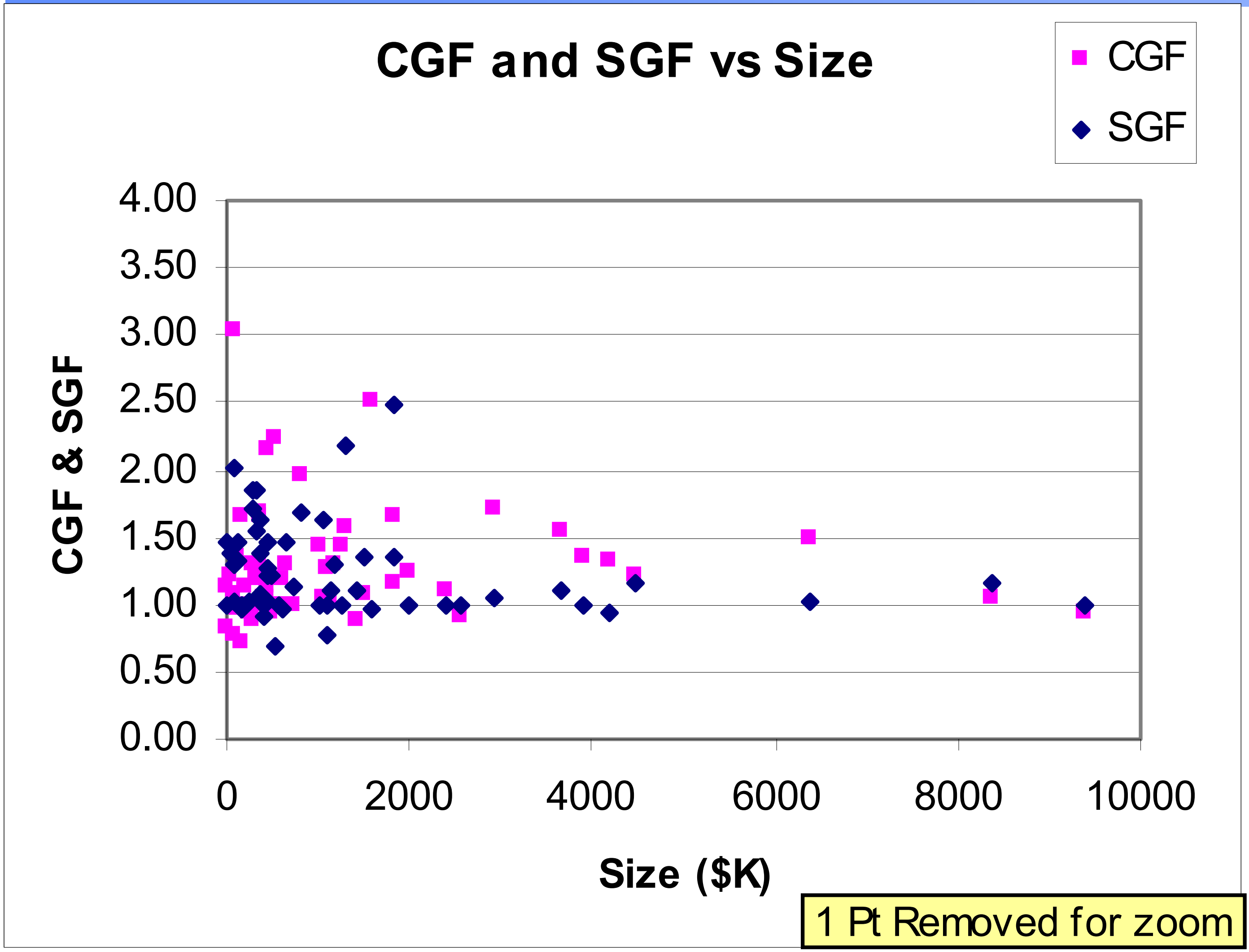
Observations

There is some dispersion and tendency to extremes

The distribution is highly skewed, as was seen in the histogram

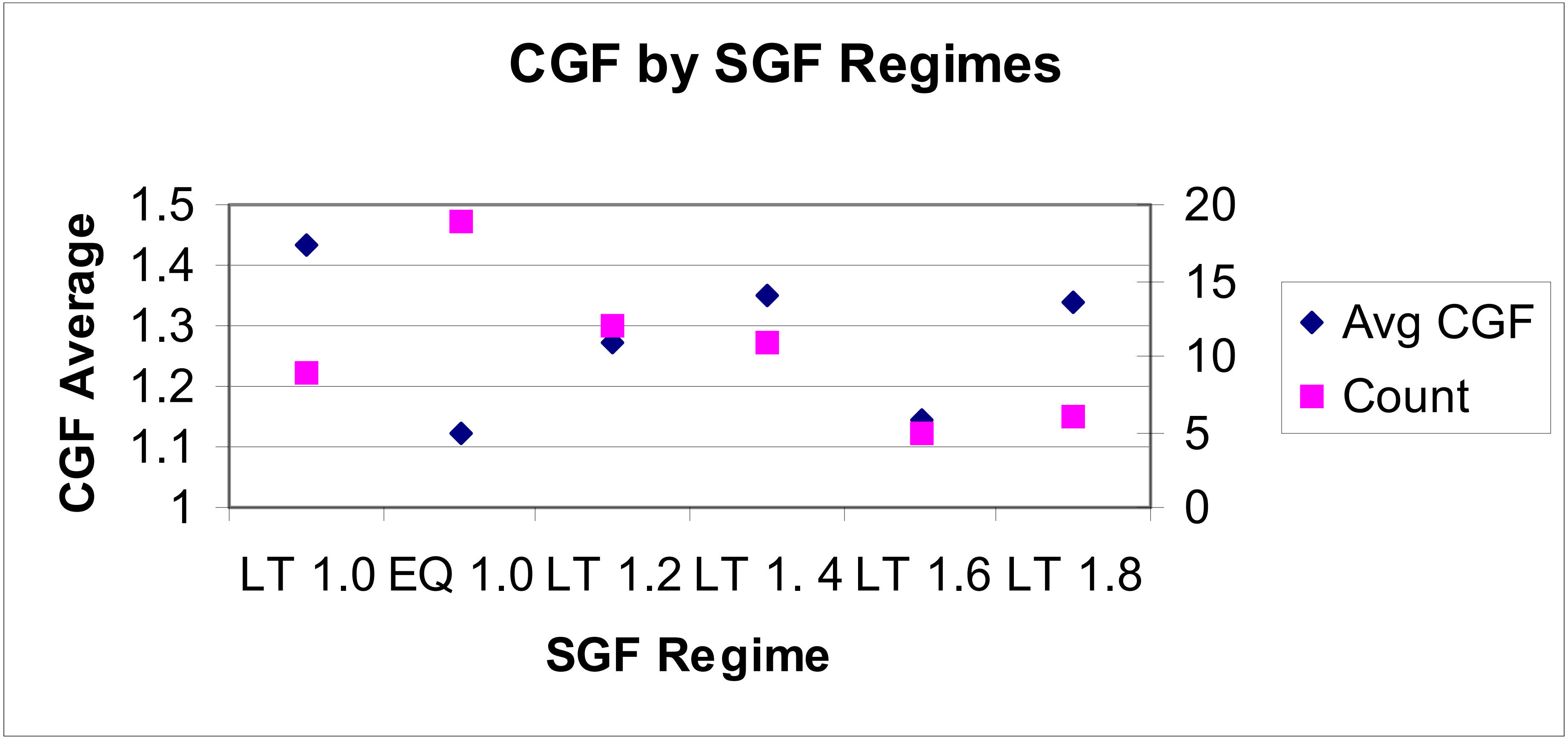
But, many programs have little-to-no growth

CGF and SGF vs. Cost Size

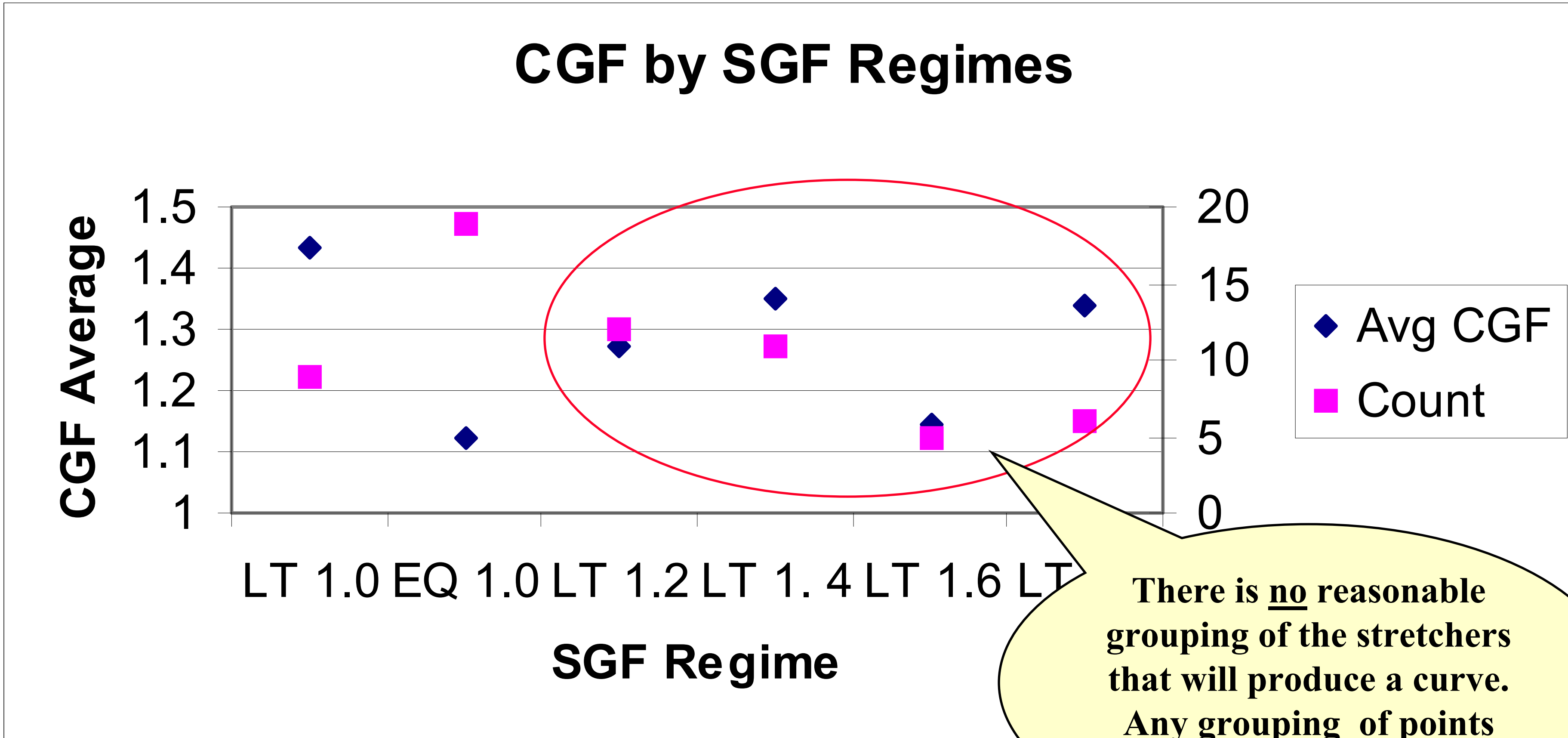


The pattern is similar, but CGF is generally more extreme:
- **Higher highs**
- **Lower lows**

CGF by Regime

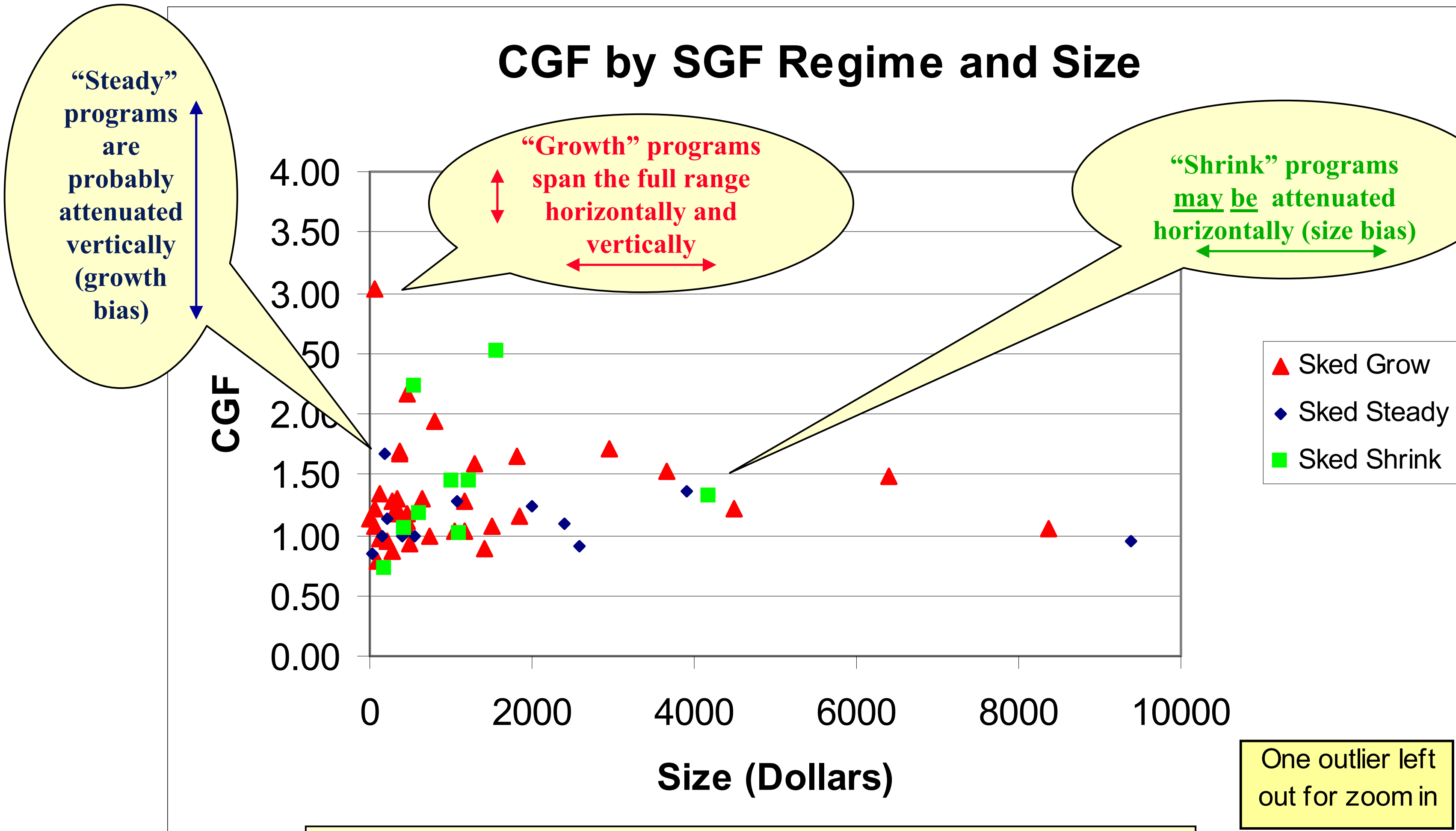


Is there a Curve?



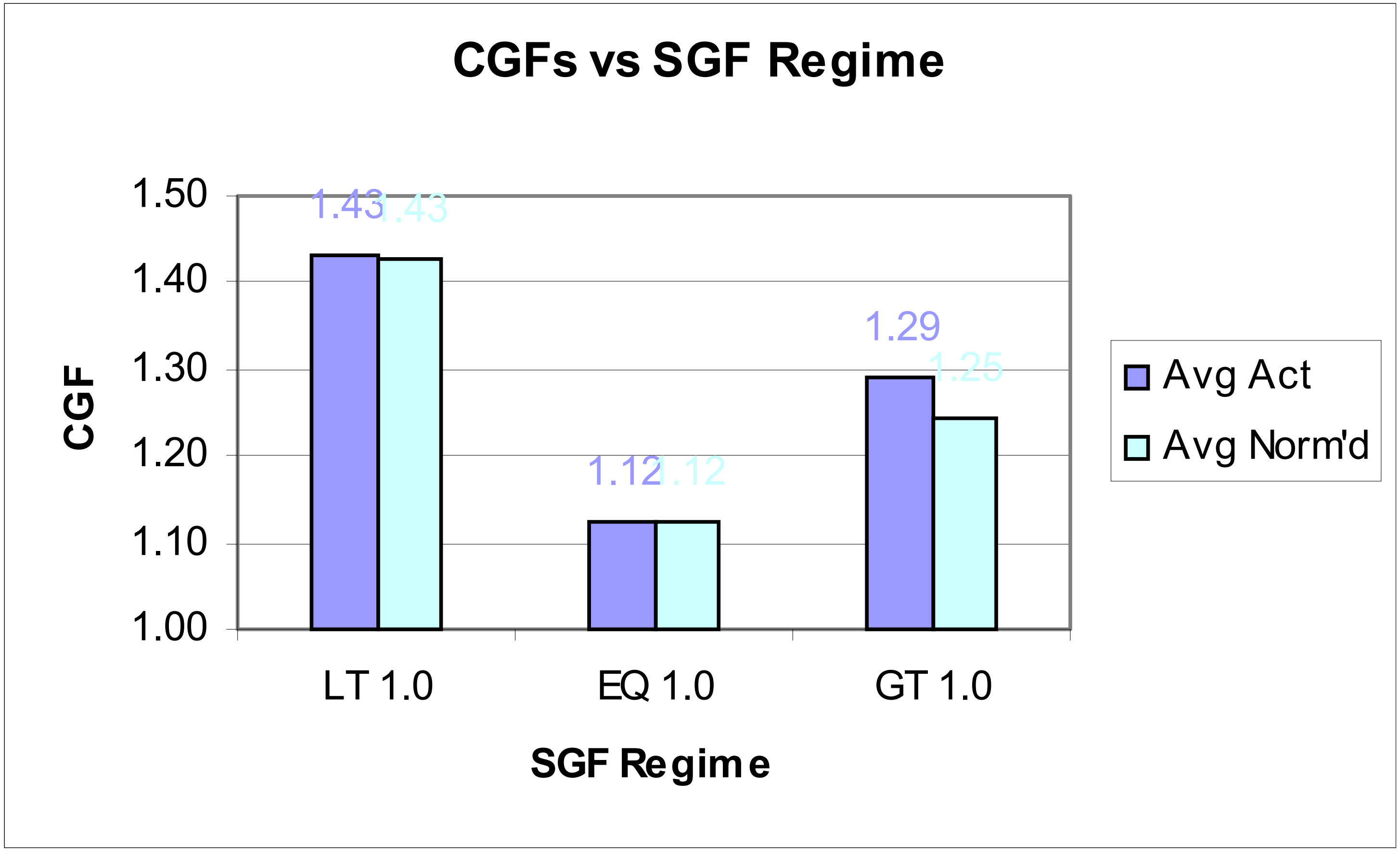
There is <u>no</u> reasonable grouping of the stretchers that will produce a curve. Any grouping of points has the <u>same average</u>.

Is there a Dollar-Size Bias?



Programs in the 3 regimes show no clear size bias, but a clear growth bias

Normed vs Actual CGFs by Regime

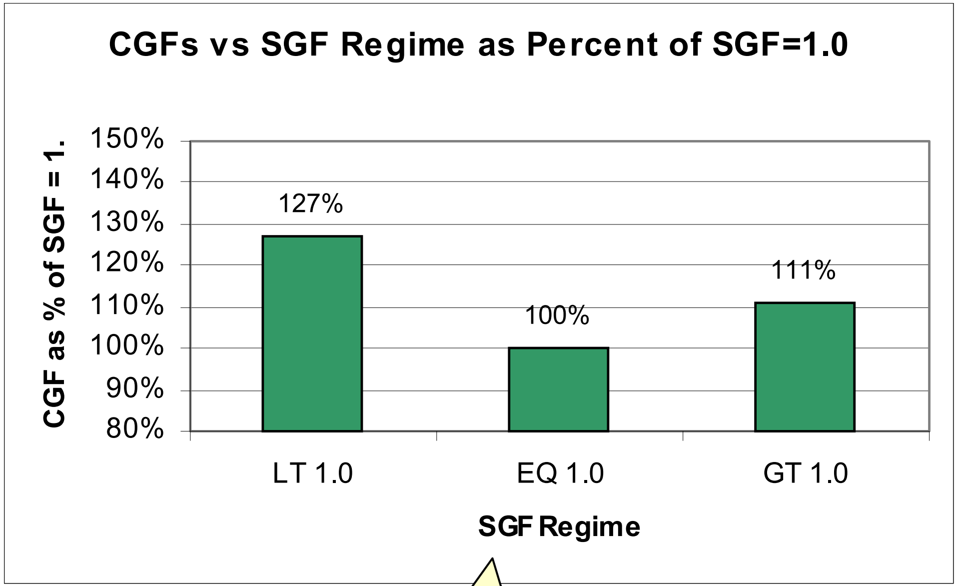


Averages for size-normed programs show the same patterns, so there is no size distortion

Note: Corrected 20 Apr 02. Minor differences

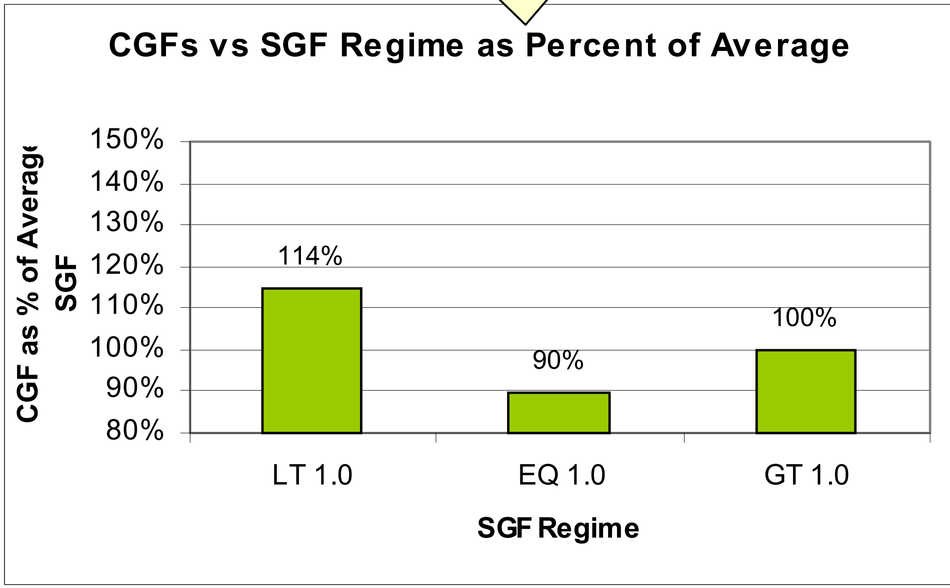
Correction Factors

- We must correct for schedule growth, if we can predict it. The form of the correction is unclear:



These factors describe what happens if schedules change

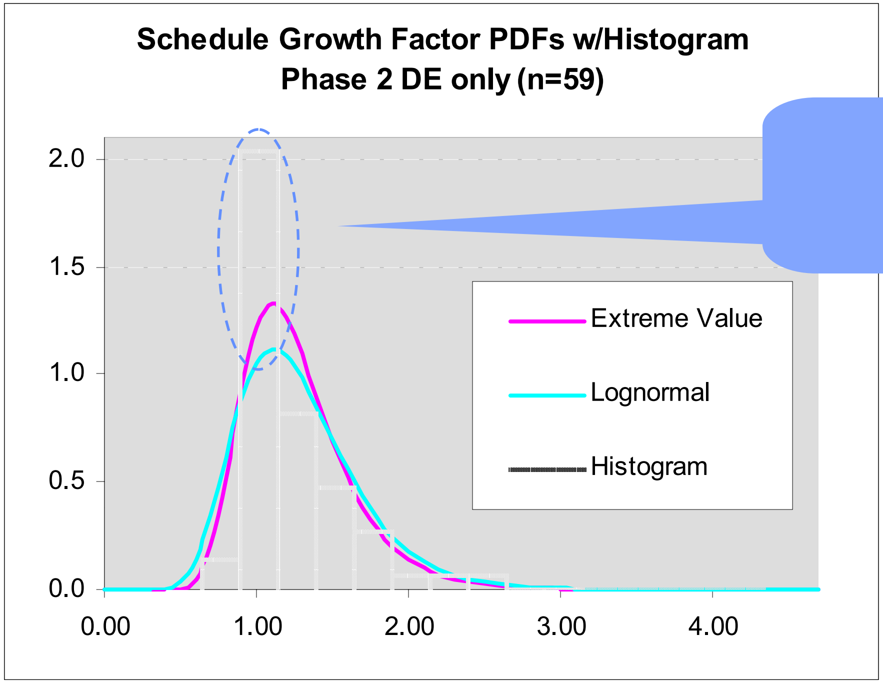
We might use these factors to correct nominal growth factors

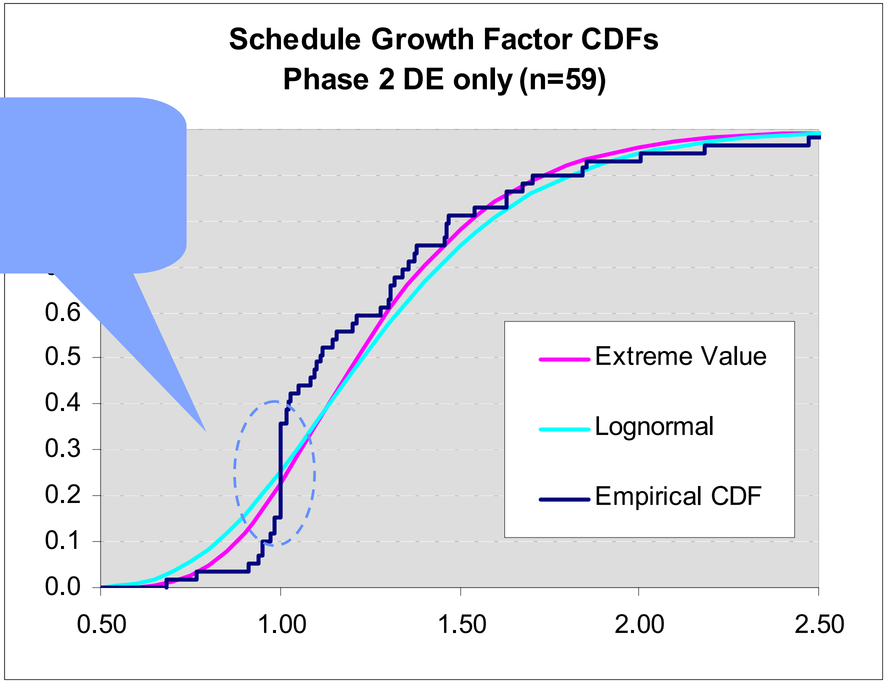


Schedule Risk

The Distribution of Schedule Risk

Best Fits vs. Empirical Data



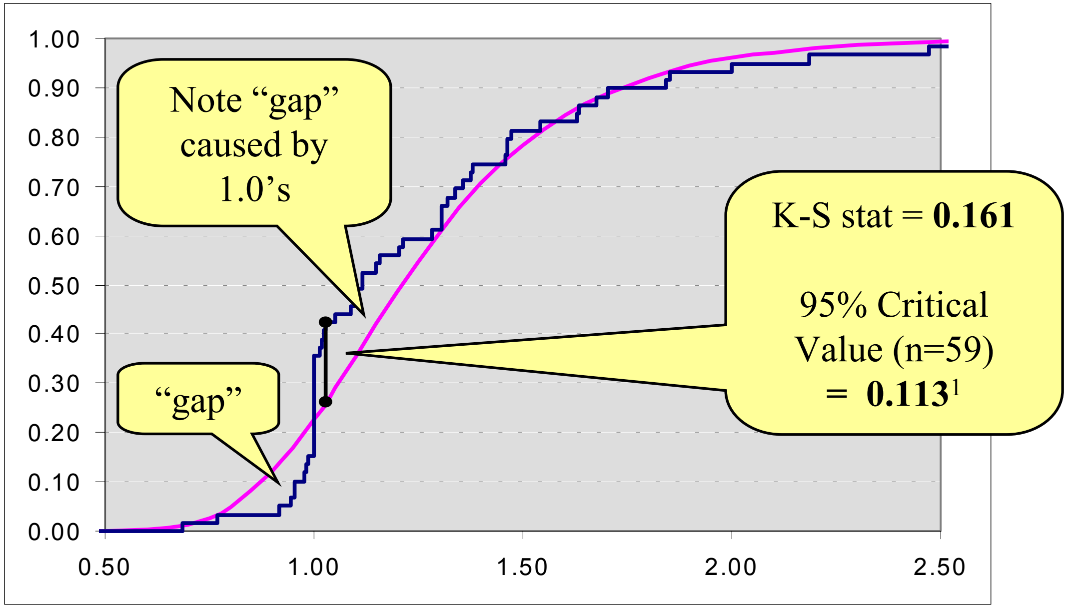


- Extreme Value Distribution is what we expect theoretically
- Extreme Value more peaked, appears to represent data better than Lognormal
- But we will see the number of 1.0's in the data base (schedules finishing "on time") creates problems in the fit statistics

Extreme Value Distribution Fit

- **The CDF of the data is oddly shaped due to a large number of 1.0's and fails a Kolmogorov-Smirnov test for the Extreme Value Distribution**

Empirical Schedule Growth CDF vs Fitted Extreme Value



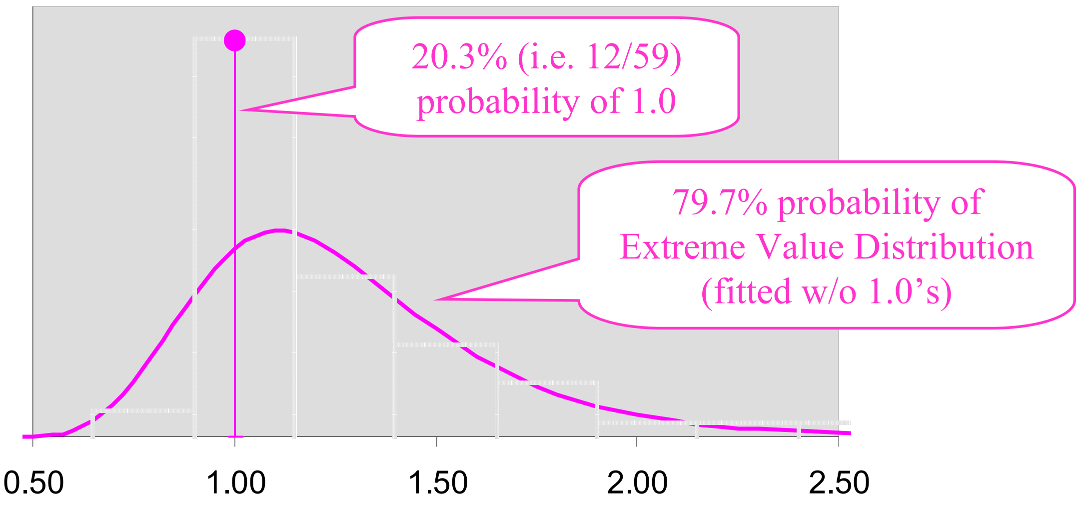
- **We believe the disproportionate amount of 1.0's is politically motivated and not a natural occurrence**
  - **This causes a "gap" between the empirical and fitted distributions**
- **We will next examine a hypothetical distribution with the 1.0's redistributed along the "gap" area (using the Ext Val fit)**

1. Lilliefors methodology applied to Extreme Value distribution to generate critical value with Monte Carlo simulation

Hybrid Distribution Alternative

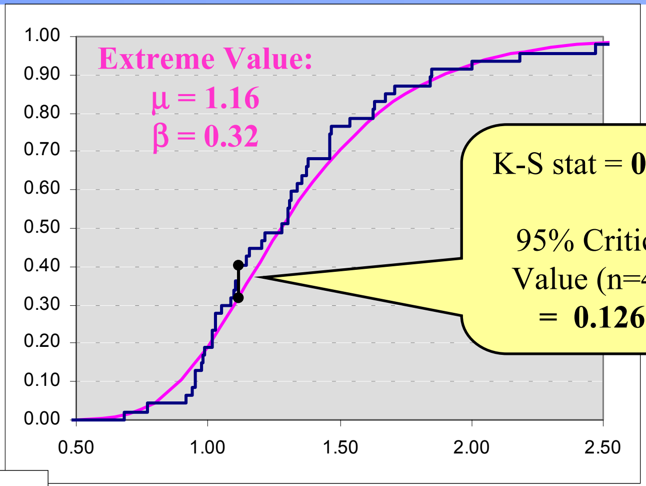
- **The hypothetical natural (re-distributed) distribution is reasonable for use**
  - **But, if you wish to capture the effects of too many programs appearing to finish "on schedule" then a hybrid distribution should be examined**
- **To do this we must consider the probability of 1.0 vs. the rest of the outcomes as discrete cases**
  - **P(1.0) = 12/59 = 20.3%**
  - **P(Extreme Value) = 79.7%**
- **The Extreme Value parameters would then be estimated from the data with the 1.0's removed**

Hybrid Schedule Growth PDF with Histogram (original SGF data)

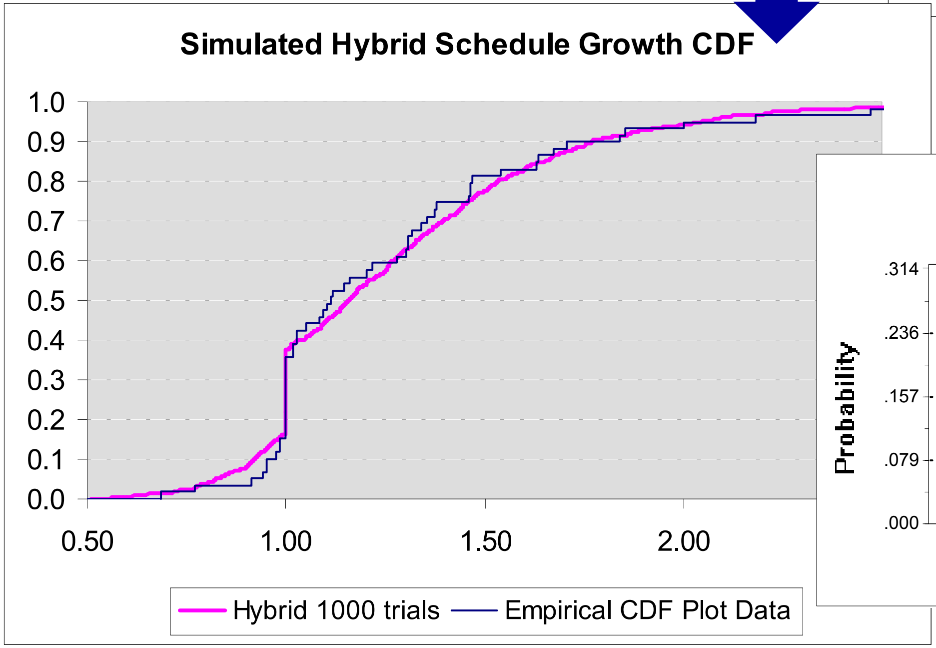


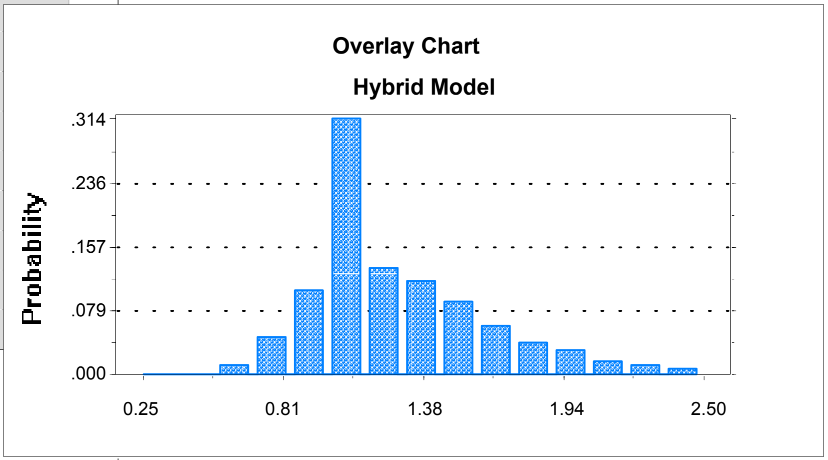
Hybrid Distribution Alternative

Extreme Value fit to data without 1.0s: K-S stat is less than the critical value. The Extreme Value is a good representation of this data.



Results of simulation combining this distribution with a discrete 20.3% probability of a 1.0





1. Lilliefors methodology applied to Extreme Value distribution to generate critical value with Monte Carlo simulation

Distribution Conclusions

- We have shown that the Extreme Value distribution is well supported as the natural distribution
- We have shown that the pieces of the hybrid distribution fit the data
  - And, the hybrid reproduces the actuals well
- We recommend using the hybrid
  - But if "political" or "cosmetic" effects are absent, we recommend using the hypothetical natural distribution

Conclusions and Resources

Overall Conclusions

- We've looked at various types of risk
  - Including several specific examples
- We've discussed some of the more common issues that arise
- We've considered some of the effects you need to be aware of
- Hopefully you are now
  - More aware of the scope of risk
  - Energized to delve into it some more
  - Able to be more discriminating when you see risk analysis

Risk Resources – Books

- *Against the Gods: The Remarkable Story of Risk*, Peter L. Bernstein, August 31, 1998, John Wiley & Sons
- *Living Dangerously! Navigating the Risks of Everyday Life*, John F. Ross, 1999, Perseus Publishing
- *Probability Methods for Cost Uncertainty Analysis: A Systems Engineering Perspective*, Paul Garvey, 2000, Marcel Dekker
- *Introduction to Simulation and Risk Analysis,* James R. Evan, David Louis Olson, James R. Evans, 1998, Prentice Hall
- *Risk Analysis: A Quantitative Guide*, David Vose, 2000, John Wiley & Sons

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Risk Resources – Web

- Decisioneering
  - Makers of Crystal Ball for Monte Carlo simulation
  - http://www.decisioneering.com
- Palisade
  - Makers of @Risk for Monte Carlo simulation
  - http://www.palisade.com

Risk Resources – Papers

- *Approximating the Probability Distribution of Total System Cost*, Paul Garvey, DoDCAS 1999
- *Why Cost Analysts should use Pearson Correlation, rather than Rank Correlation*, Paul Garvey, DoDCAS 1999
- *Why Correlation Matters in Cost Estimating* , Stephen Book, DoDCAS 1999
- *General-Error Regression in Deriving Cost-Estimating Relationships*, Stephen A. Book and Mr. Philip H. Young, DoDCAS 1998
- *Specifying Probability Distributions From Partial Information on their Ranges of Values,* Paul R. Garvey, DoDCAS 1998
- *Don't Sum EVM WBS Element Estimates at Completion,* Stephen Book, ISPA/SCEA 2001
- *Only Numbers in the Interval –1.0000 to +0.9314… Can Be Values of the Correlation Between Oppositely-Skewed Right-Triangular Distributions*, Stephen Book , ISPA/SCEA 1999

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Risk Resources – Papers

- *An Overview of Correlation and Functional Dependencies in Cost Risk and Uncertainty Analysis,* R. L. Coleman, S. S. Gupta, DoDCAS, 1994
- *Weapon System Cost Growth As a Function of Maturity,* K. J. Allison, R. L. Coleman, DoDCAS 1996
- *Cost Risk Estimates Incorporating Functional Correlation, Acquisition Phase Relationships, and Realized Risk,* R. L. Coleman, S. S. Gupta, J. R. Summerville, G. E. Hartigan, SCEA 1997
- *Cost Risk Analysis of the Ballistic Missile Defense (BMD) System, An Overview of New Initiatives Included in the BMDO Risk Methodology,* R. L. Coleman, J. R. Summerville, D. M. Snead, S. S. Gupta, G. E. Hartigan, N. L. St. Louis, DoDCAS, 1998 (Outstanding Contributed Paper) and ISPA/SCEA 1998

Risk Resources – Papers

- *Risk Analysis of a Major Government Information Production System, Expert-Opinion-Based Software Cost Risk Analysis Methodology,* N. L. St. Louis, F. K. Blackburn, R. L. Coleman, DoDCAS, 1998 (Outstanding Contributed Paper), and ISPA/SCEA 1998 (Overall Best Paper Award)
- *Analysis and Implementation of Cost Estimating Risk in the Ballistic Missile Defense Organization (BMDO) Risk Model, A Study of Distribution*, J. R. Summerville, H. F. Chelson, R. L. Coleman, D. M. Snead, ISPA/SCEA 1999
- *Risk in Cost Estimating - General Introduction & The BMDO Approach*, R. L. Coleman, J. R. Summerville, M. DuBois, B. Myers, DoDCAS, 2000
- *Cost Risk in Operations and Support Estimates*, J. R. Summerville, R. L. Coleman, M. E. Dameron, SCEA 2000

Risk Resources – Papers

- *Cost Risk in a System of Systems,* R.L. Coleman, J.R. Summerville, V. Reisenleiter, D. M. Snead, M. E. Dameron, J. A. Mentecki, L. M. Naef, SCEA 2000
- *NAVAIR Cost Growth Study: A Cohorted Study of the Effects of Era, Size, Acquisition Phase, Phase Correlation and Cost Drivers,* R. L. Coleman, J. R. Summerville, M. E. Dameron, C. L. Pullen, D. M. Snead, ISPA/SCEA 2001
- *Probability Distributions of Work Breakdown Structures,* R. L. Coleman, J. R. Summerville, M. E. Dameron, N. L. St. Louis, ISPA/SCEA 2001
- *Relational Correlation: What to do when Functional Correlation is Impossible,* R. L. Coleman, J. R. Summerville, M. E. Dameron, C. L. Pullen, S. S. Gupta, ISPA/SCEA 2001
- *The Relationship Between Cost Growth and Schedule Growth,* R. L. Coleman, J. R. Summerville, DoDCAS, SCEA 2002
- *The Manual for Intelligence Community CAIG Independent Cost Risk Estimates,* R. L. Coleman, J. R. Summerville, S. S. Gupta, DoDCAS, SCEA 2002
- *Modeling the Effect of Program Size on Cost Growth*, M.E. Dameron, R.L. Coleman, J.R. Summerville, C.L. Pullen, D.M. Snead, SCEA 2002

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Special Topics in Cost Risk

Predicting EAC[1]

Using Current CPI and Percent Complete

1. Predicting Final CPI, R.L. Coleman, M.E. Dameron, J.R. Summerville, H. F. Chelson, S. L. Van Drew, SCEA 2003

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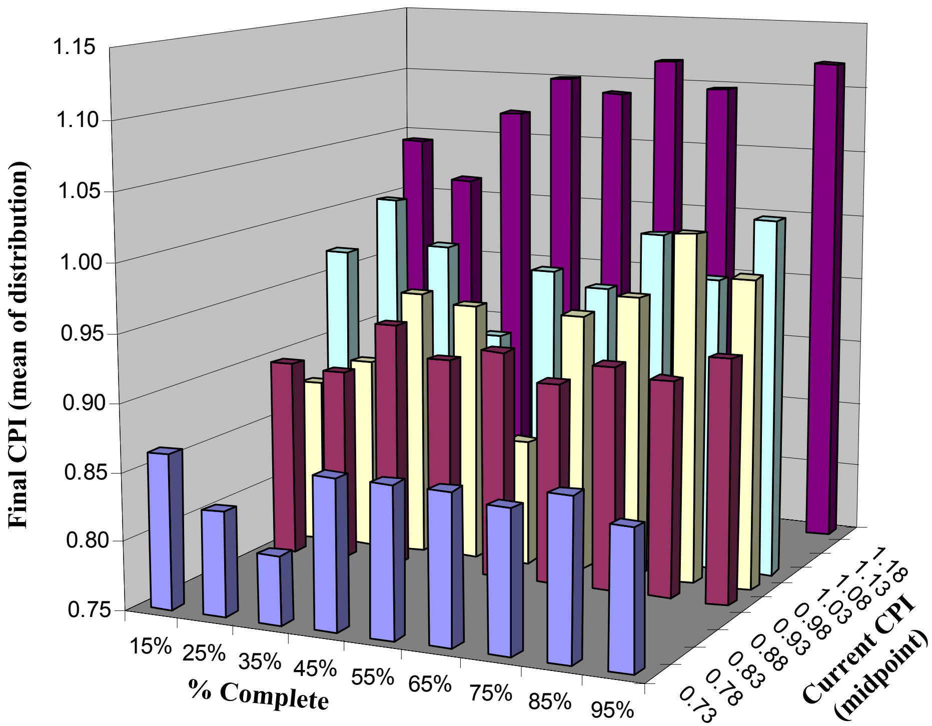
The Predictions - Development

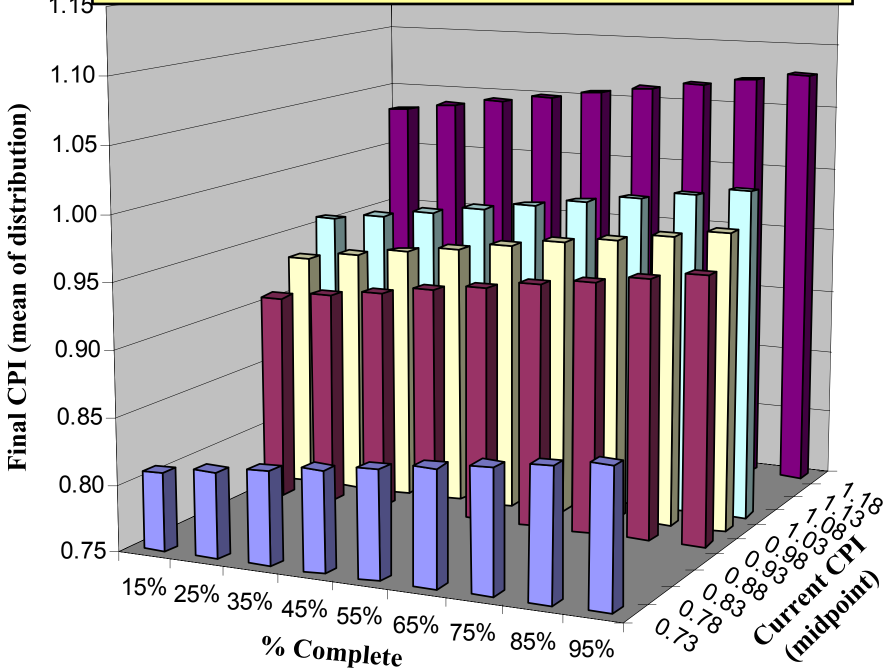
Warning: The % Complete axis is not a time axis, it is an initial condition axis

Raw Data



Prediction Equation

Final CPI = 0.438 + 0.057(% Complete) + 0.497(Current CPI)



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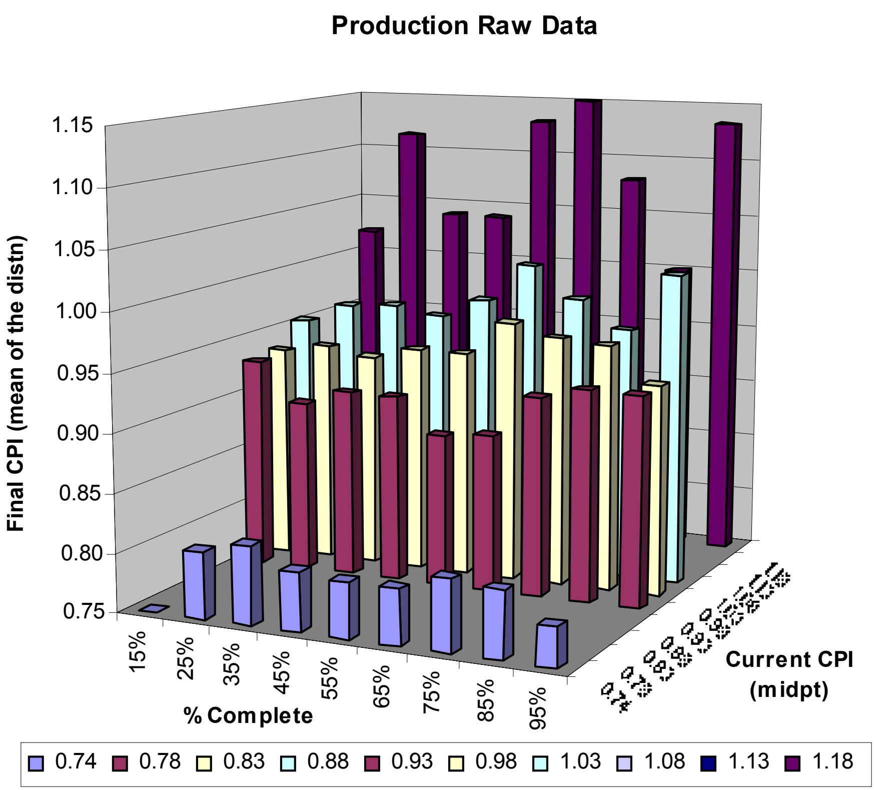
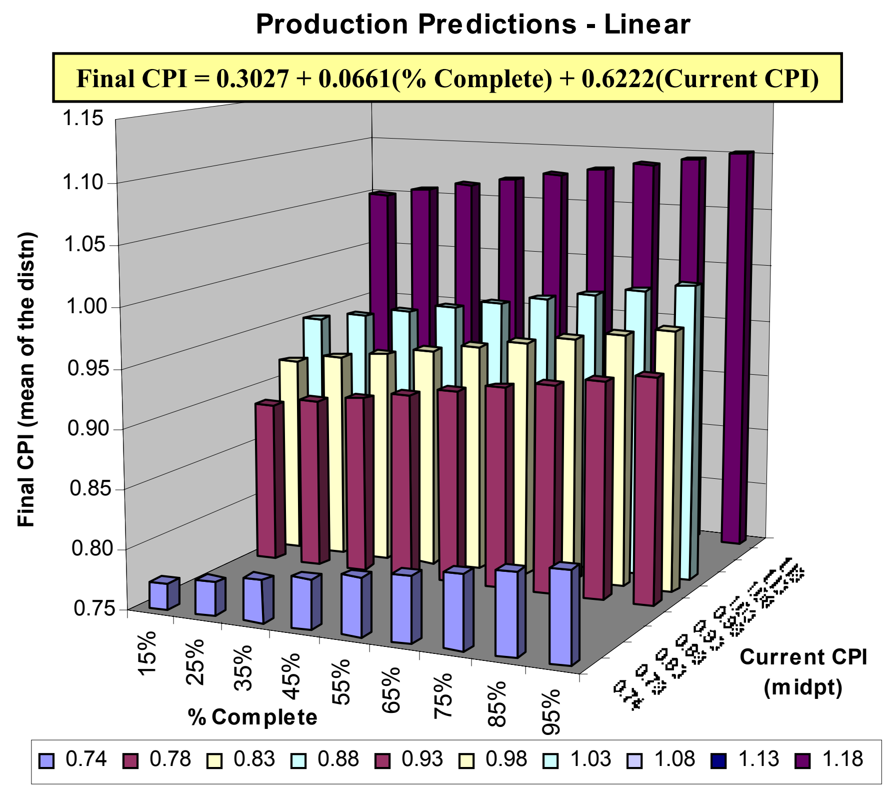
The Predictions - Production

Warning: The % Complete axis is not a time axis, it is an initial condition axis





EVM Tool

Current CPI	**0.90**	input
% Complete	**50%**	input
Development or Production	**Dev**	input
EAC CPI:	0.91	result
CV:	10%	result
If a confidence interval is desired other than +/- one standard deviation indicate here:	*68.3%*	default +/- 1 std dev is 68.3%

Probability of achieving CPI

Target EAC CPI:	**0.95**	input
% Probability	34%	result
% Probability	**80%**	input
Target EAC CPI:	0.84	result

EAC CPI	CPI	% Probability
Upper cost bound:	0.82	84%
Mean:	**0.91**	**50%**
Lower cost bound:	1.00	16%

ETC CPI	CPI	% Probability
Upper cost bound:	0.84	84%
Mean:	**0.93**	**50%**
Lower cost bound:	1.02	16%

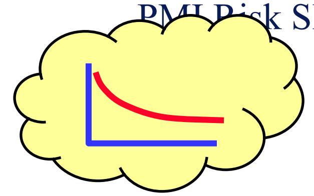
Size Adjustments

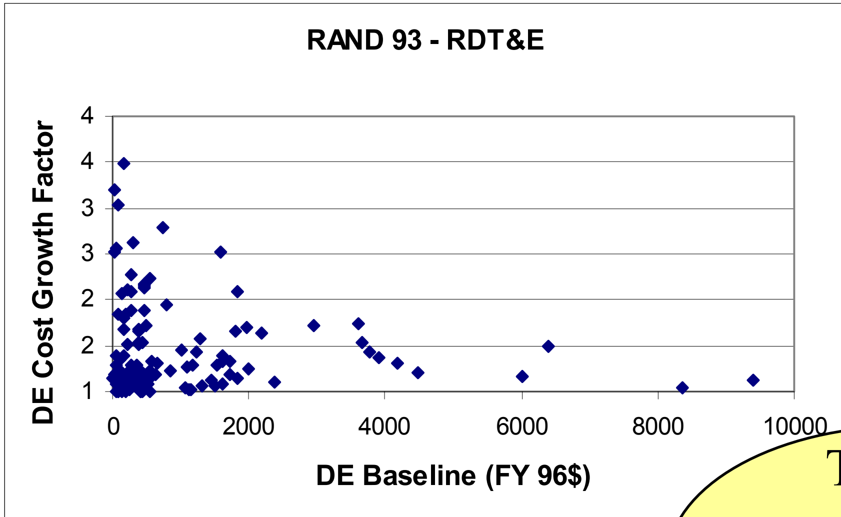
How to account for program size in Risk[1]

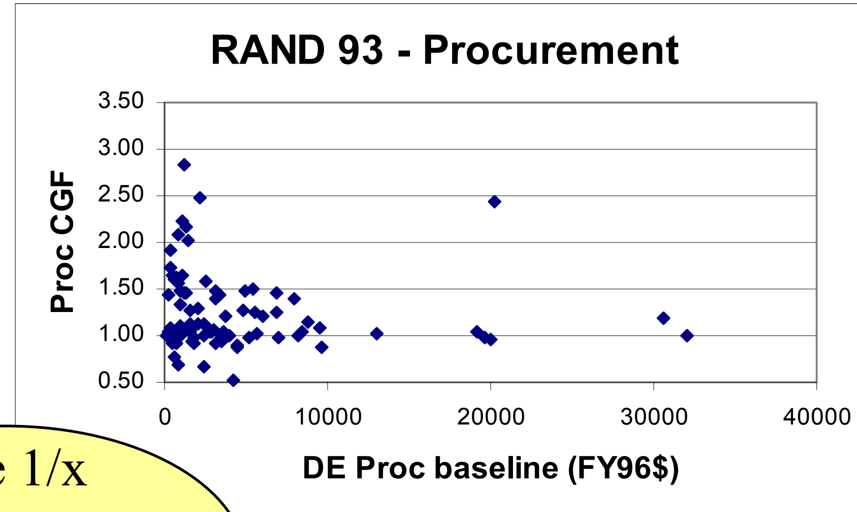
1. Modeling the Effect of Program Size on Cost Growth, M.E. Dameron, R.L. Coleman, J.R. Summerville, C.L. Pullen, D.M. Snead, SCEA 2002

The "1/x Pattern"

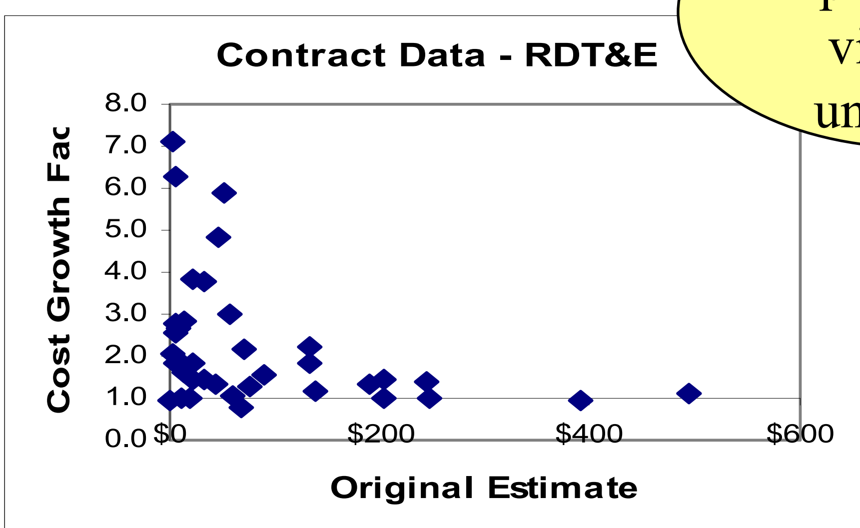
Cost Growth Factor vs. Baseline Cost

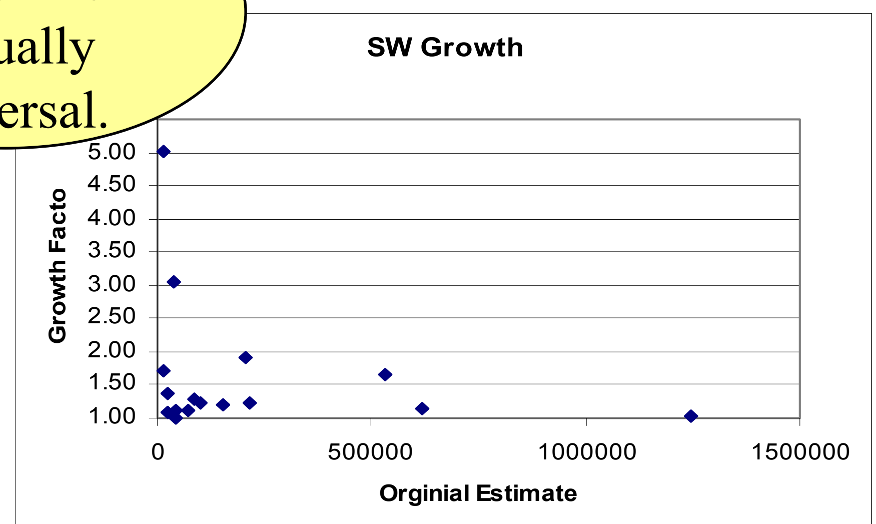




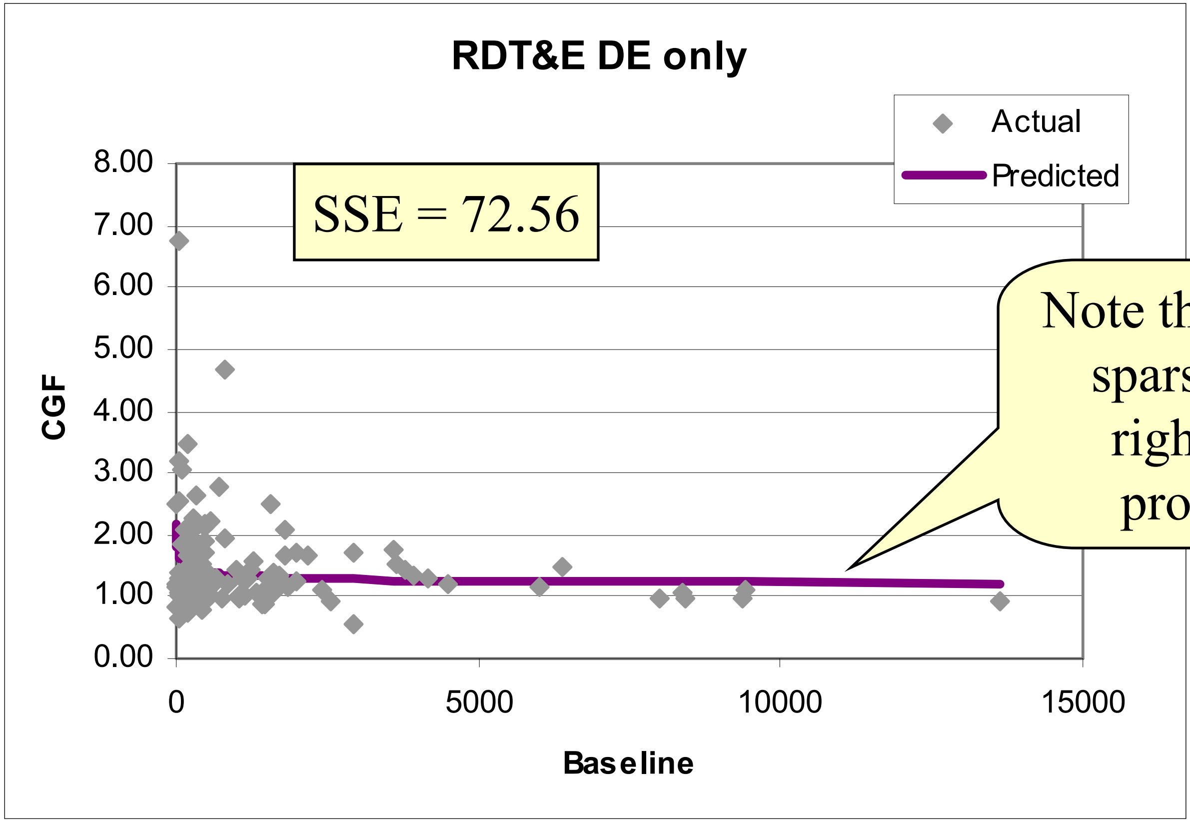


The 1/x pattern is virtually universal.



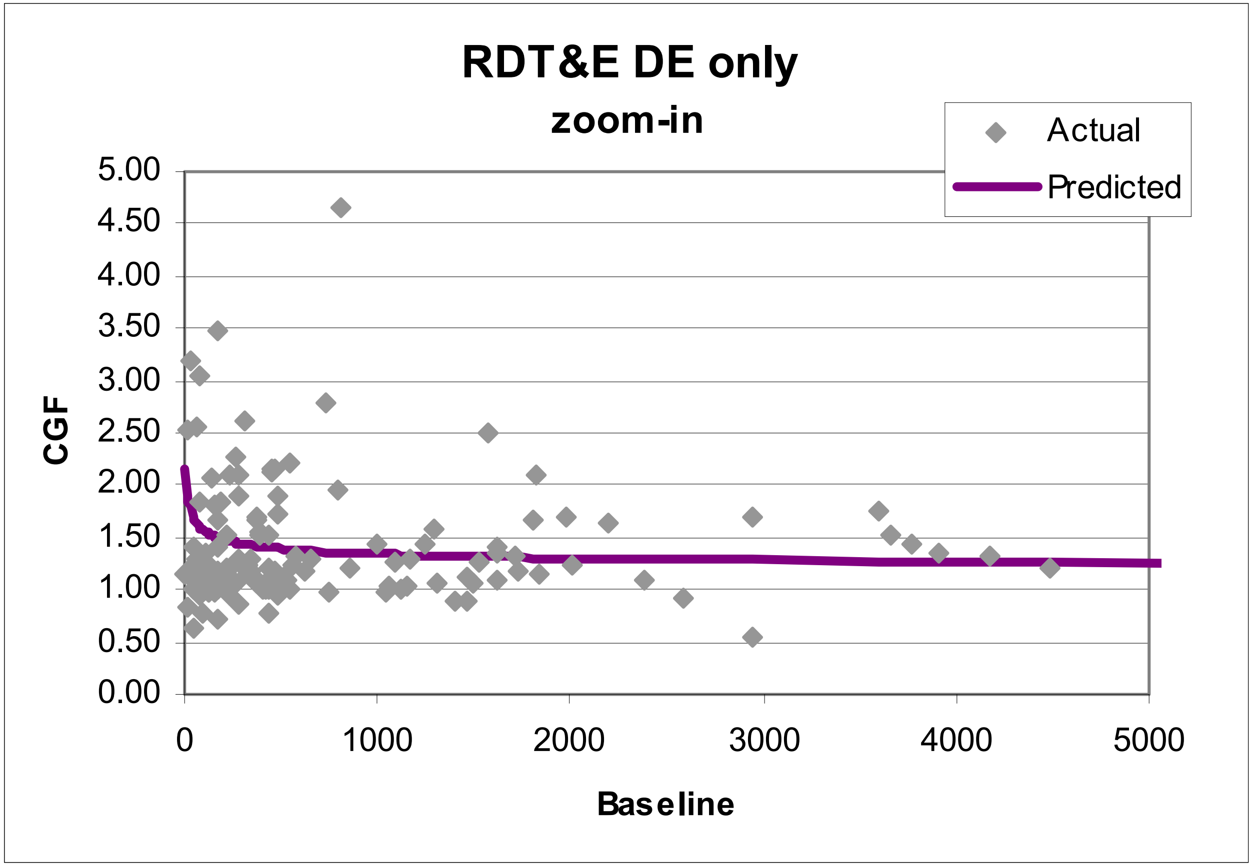


Prediction Equation - RAND RDT&E



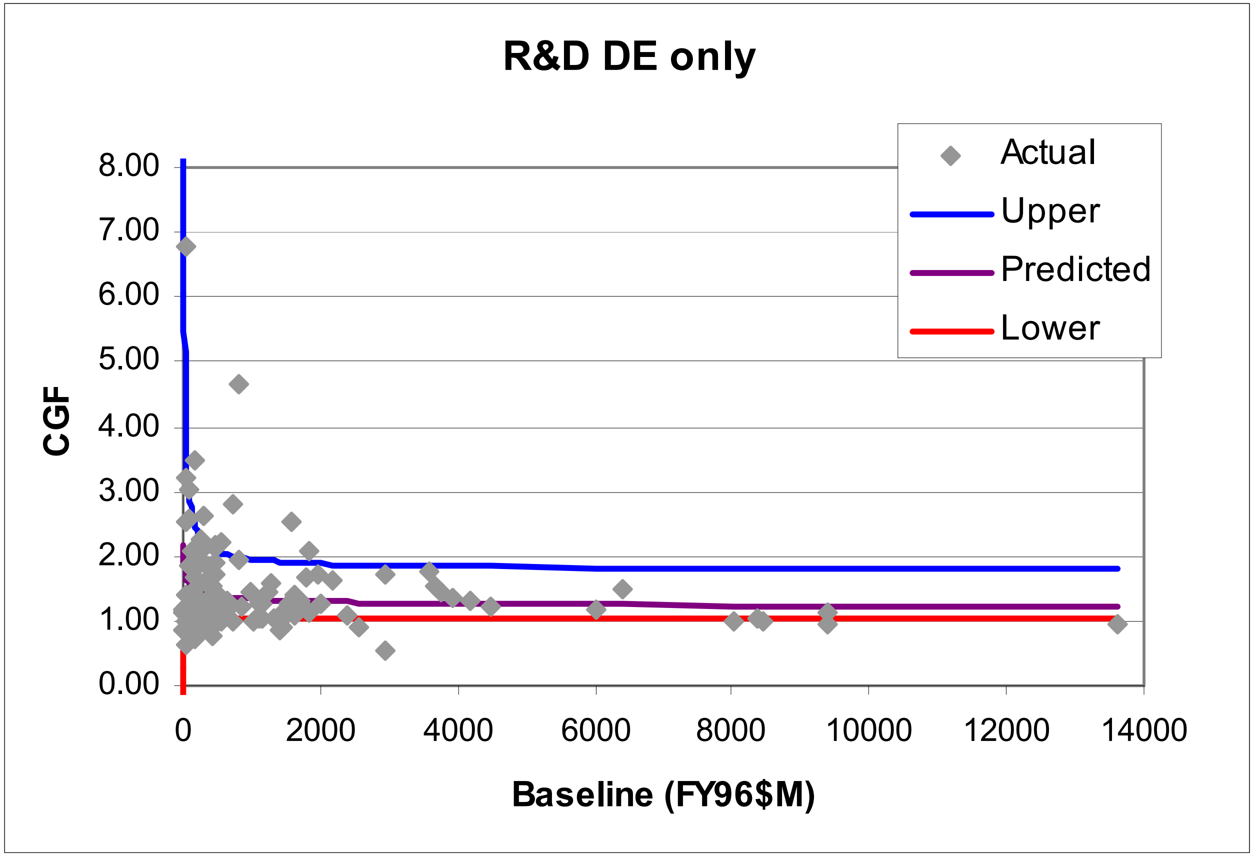
RDT&E Predicted CGF = 1.8 * (MSII Baseline FY96$M)$^{-0.3}$ + 1.1

Prediction Equation - RAND RDT&E



RDT&E Predicted CGF = 1.8 * (MSII Baseline FY96$M)$^{-0.3}$ + 1.1

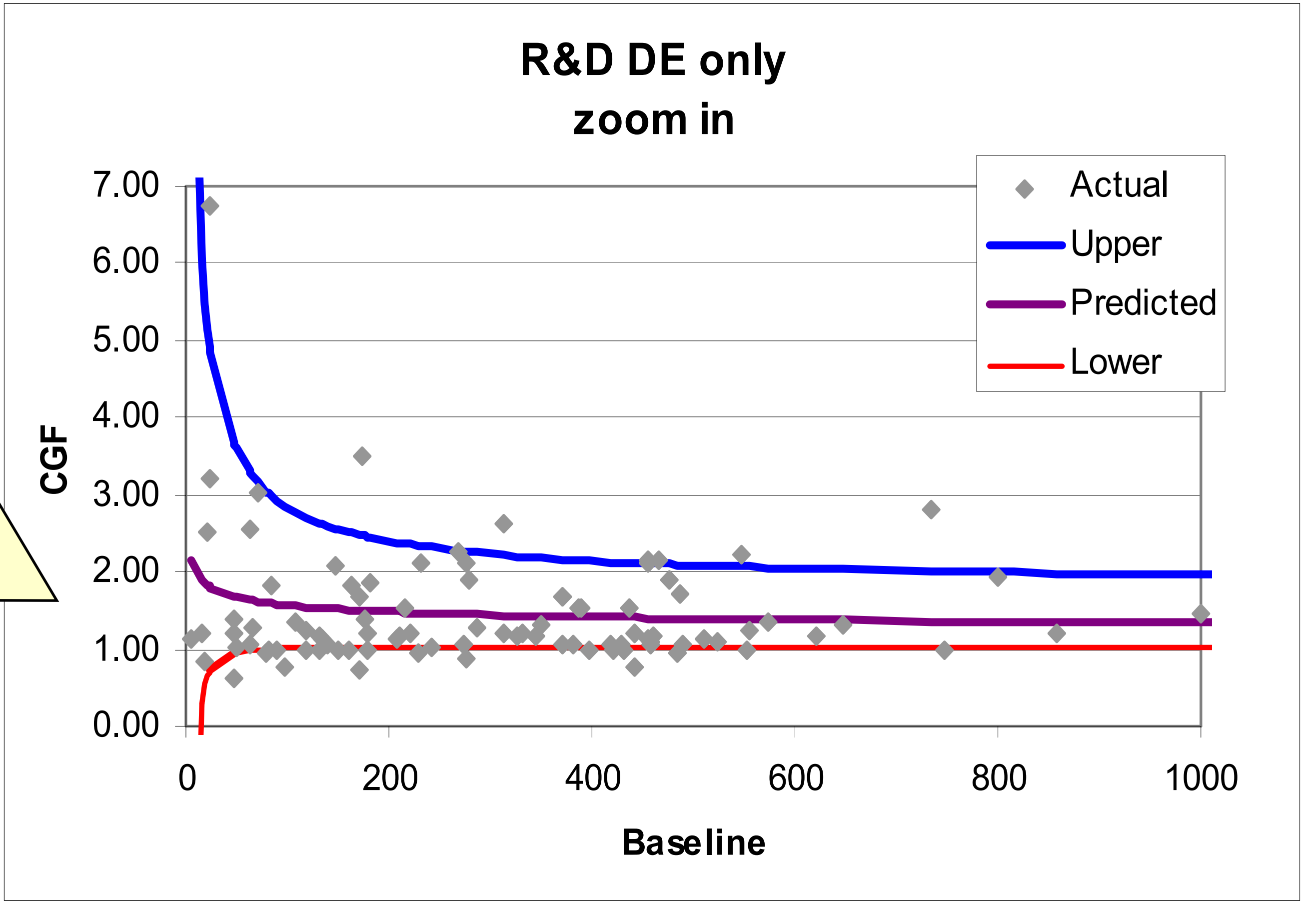
Dispersion – Bounds



This graph shows the actual data, the CGF prediction line, and the bounds. The next slide will zoom-in.

Dispersion – Bounds

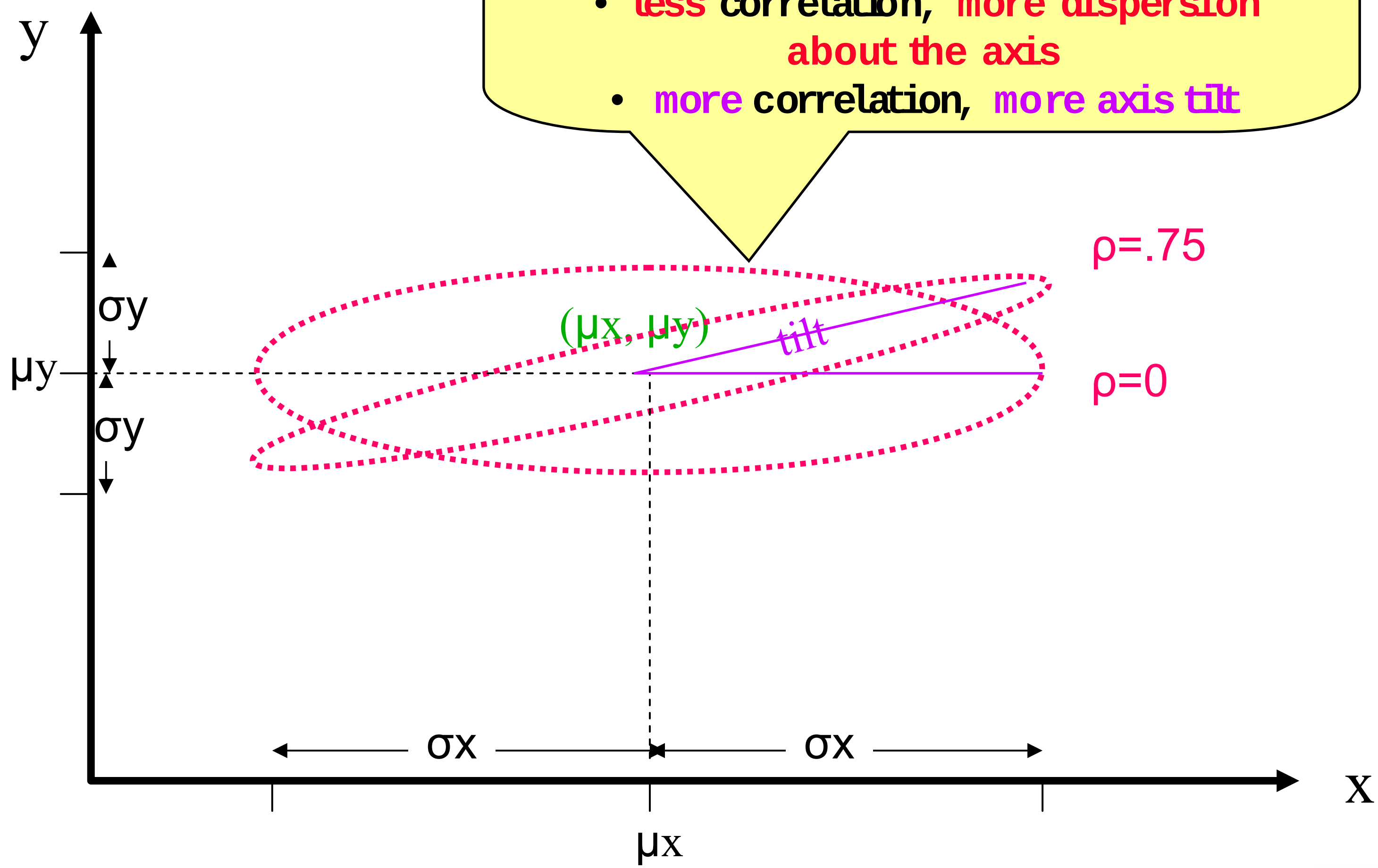
Note that the Upper and Lower bounds are not symmetric. Also, dispersion is higher for smaller projects … an effect that is captured by the bounds.



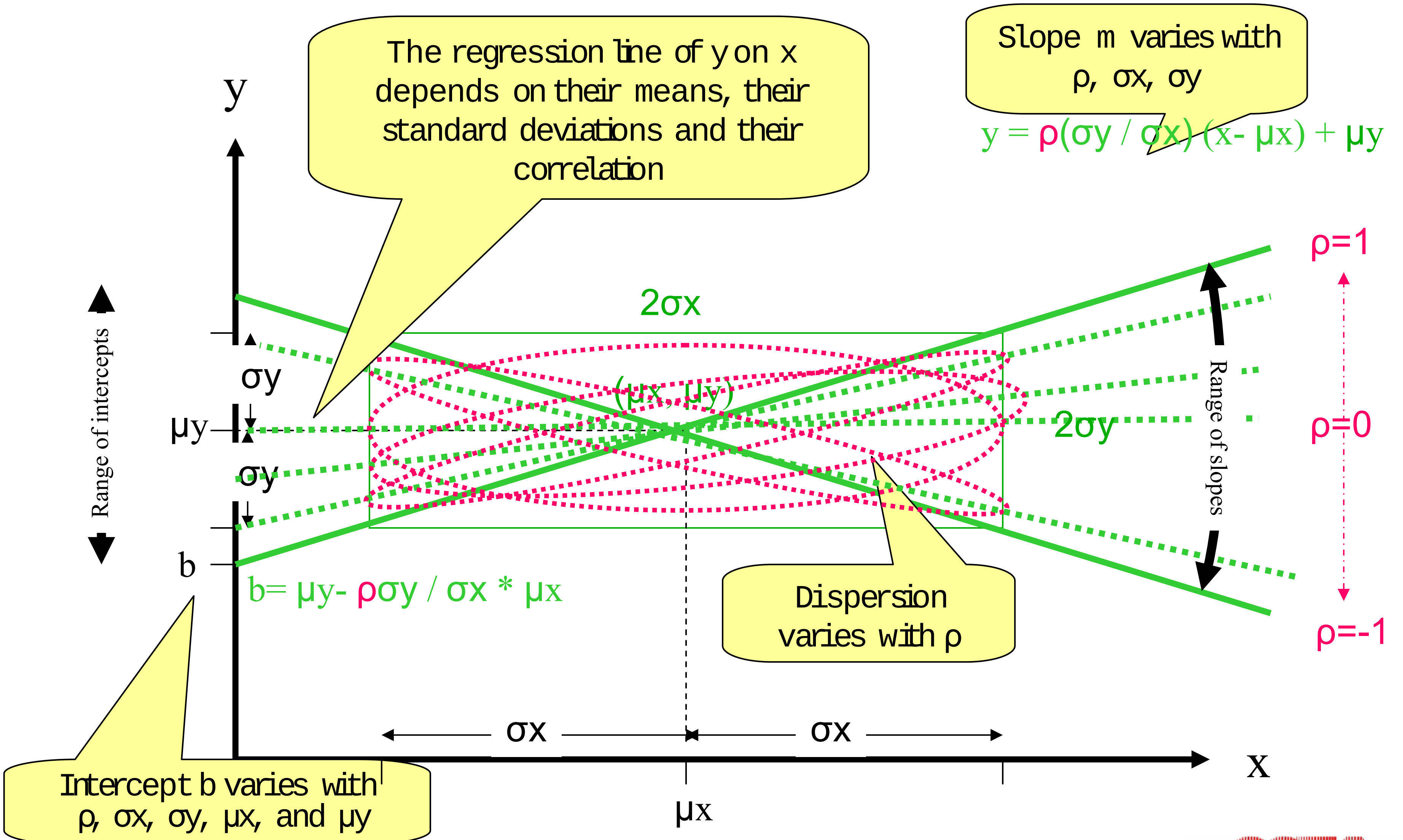
Advanced Topics

Geometry of Bivariate Normal Random Variables

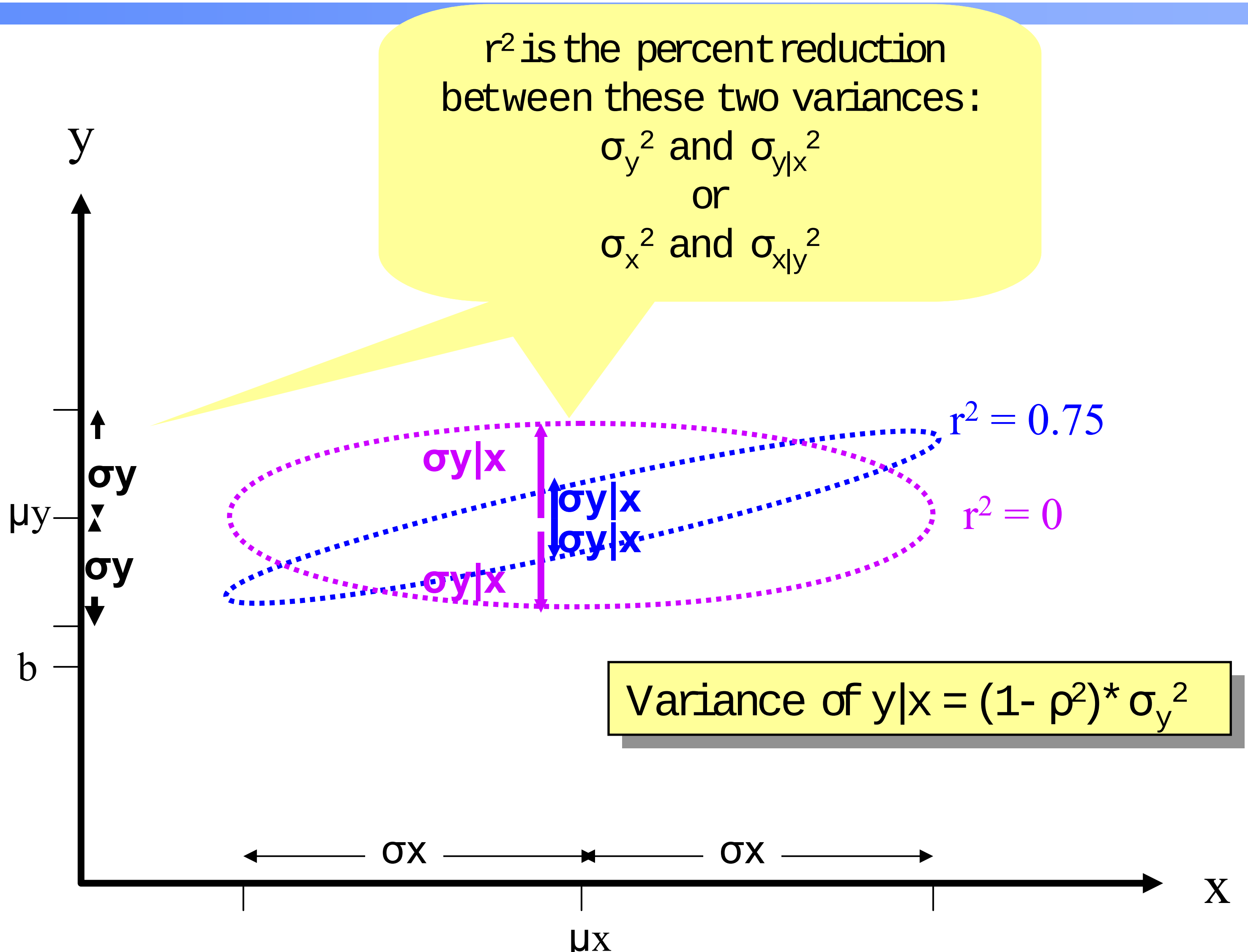
The dispersion and axis tilt of the "data cloud" is a function of correlation:
- less correlation, more dispersion about the axis
- more correlation, more axis tilt



Geometry of Regression Line



Geometry of r squared



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Backup

Modifying the Risk Cube Method

Known problems

SME issues:

1. Does not account for events that are unforeseen by SMEs (unknown unknowns)
2. Difficult to do for independent SMEs, due to insufficient familiarity with the program
   - SMEs attached to the program tend to be optimistic
3. Unclear whether SMEs know cost impacts
4. Small problems are hard to enumerate; however, many little issues can add up
   - Some risk is often missing
5. Vulnerable to ax-grinding and hobby horsing

Analytic issues:

1. Likelihood and Consequence scores must be defined as probabilities (% chance of risk item occurring) and cost impacts (% cost growth)
2. Cost and dispersion understated because correlation is unlikely to be handled
   - Hard to handle, as correlation methods are based on continuous, not discrete random variables
3. Costs understated because the method often lacks “Below-the-Line” (BTL) impacts like Program Management

Proposed solutions are available for each issue …

Modifying the Risk Cube Method

Known problems – some solutions

1. Likelihood and Consequence scores must be defined as probabilities (% chance of risk item occurring) and cost impacts (% cost growth)

Solution:

- If risk scores are not currently defined in terms of percents, we can use a standard 5 point scoring matrix (see later slides)

2. Cost and dispersion understated because correlation is unlikely to be handled
   - Hard to handle, as correlation methods are based on continuous, not discrete R.V.s

Solution: Item-to-item correlation?

- Inject correlations between items using Relational Correlation?
- Still under consideration

3. Costs understated because the method often lacks "Below-the-Line" impacts like SE/PM (This is often true in risk, but is particularly common in this method)

Solution: Item-to-Below-the-Line correlation and BTL Inclusion

- Connect risk items with CWBS lines
- Convert to a continuous distribution?
- Insert Below-the-Line costs
- Inject Functional Correlation between Items and "Below-the-Line" cost

… rendered much more difficult if items are not connected to CWBS

Historical Cost Growth

	Raw Average			$ Wtd Average				During Prod
Source	**Tot**	**R&D**	**Prod**	**Tot**	**R&D**	**Prod**	**N**	**Prod**
RAND 93:	**1.30**			**1.20**	1.25	1.18	**100+**	1.02
CAIG 91:	**1.33**	**1.40**	**1.25**	**1.21**	1.24	1.19	**27**	
TASC 94:		**1.49**	**1.54**				**20+**	
TASC 96:		**1.43**	**1.55**		1.21	**1.35**	**14**	0.99
Christensen 99:				**1.09**	1.14			1.06 *MSIII*

This chart presents data from different eras & different data base subsets
The message it conveys is a general similarity, not precise equality

1. All data are from DoD SARs, under generally the same rules and procedures, except for Christensen.
2. Christensen data is EVM Data, which includes re-baselining.
3. This cost growth data includes growth due to “Cost Estimating Errors”.
4. RAND Data and CAIG Data are from MS I, TASC data is from MSII.

Pf/Cf - Thoughts on Distribution

- The underlying distribution in the Pf/Cf model is Bernoulli
  - A risk item either occurs or it does not (discrete random variables)
  - Correlation and functional correlation are hard Without these:
    - Std Dev is too tight
    - BTL risk is not captured
  - We could just allow the BTLs to be a function of the IPE plus the risk
    - In other words, when the risk is realized, add the BTL impacts, and when it does not, omit them.
    - This would introduce some distortions … we'd rather inject functional correlation into continuous distributions, because it makes the dispersion more accurate and is better understood